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THE BREEDING OF SORGHUM IN EAST AFRICA

I. WEEVIL RESISTANCE IN SORGHUM GRAINS

H. DOGGETT

(*Agricultural Department, Tanganyika*)

Summary

A method of estimating the rates of weevil damage to the grains of different sorghum varieties is described. A positive association appears to exist between a low rate of loss from weevil damage and a thick corneous outer endosperm shell in the grain: small grains also suffer less damage than large ones. It seems that selection for weevil resistance in the field may be done by judging the thickness of the corneous shell in ripe grains.

THE work reported here was done at Ukiriguru Experimental Station, which is situated to the south of Mwanza, near Lake Victoria. The climate is characterized by a single, very variable rainy season, and a long dry season. Mean monthly maximum temperatures vary between 80 and 87° F., corresponding minimum temperatures between 59 and 66° F. The mean monthly relative humidity varies from 60 to 88 per cent. at 08.30 hours, and 37 to 67 per cent. at 14.30 hours: the humidity is low from June to October.

In many areas of Tanganyika where the rainfall is uncertain, there is a need for early-maturing sorghums which store well. In order to breed such sorghums, a character which would permit the easy recognition of good storing grains is required. The major part of the insect damage in store is due to the rice weevil (*Calandra oryzae*), associated with the flour beetle (*Tribolium castaneum*); grain moth (*Sitotroga cerealella*) can also cause appreciable damage, and it appears that the keeping qualities of sorghum grains are reduced by grain-mould attack in the field. This paper is concerned only with the weevil resistance of mould-free grain.

Experimental Details

Tests were made by enclosing 100 grains of a sorghum variety in a small net bag: one bag of each variety was buried at random in a bulk of weevily grain contained in a 4-gallon petrol tin, open at the top. In replicated trials, the bags and tins were treated as plots and blocks respectively. Counts were done at 2- to 4-week intervals, damaged and sound grains being returned to the bags after counting; the bags were returned to the appropriate tin at random, so that their positions in the bulk of weevily grain in any one tin were altered after each count. Differences in rate of damage were often large between tins, but were consistent within tins.

Preliminary Tests

Extracts from a few tests done in the years 1949 to 1951 are shown in Table 1. The grain of Dobbs and P. 41 is reputed by the local people to keep badly, while that of Wiru is said to keep well. This is reflected in these tests, which are reasonably consistent.

Typical curves for rate of loss in six varieties are shown in Fig. 1,

[Empire Journ. of Exper. Agric., Vol. 25, No. 97, 1957.]

TABLE 1. *Percentages of Damaged Grain in Storage Tests*

Sorghum varieties (a)	*1.9.49–12.1.50 Unreplicated*	*7.9.49–13.1.50 2 replications*	*11.7.50–19.9.50 11 replications*	*16.7.51–24.9.51 7 replications*
Wiru . . .	8·5 (*b*)	6·3 (*c*)	2·6	6·9
P. 41 . . .	19	15	32·9	*
Dobbs . . .	32	19·5	*	22·1

(*a*) A brief note on sorghum varieties named in the paper is given in an appendix.
(*b*) Mean of 2 Wiru strains.
(*c*) Mean of 4 Wiru strains.
* Not included in the test.

using figures from the trial reported in Table 2. It will be seen that the rates of loss differ consistently, and the experiment could have been stopped at any point without affecting the order in which the varieties were placed.

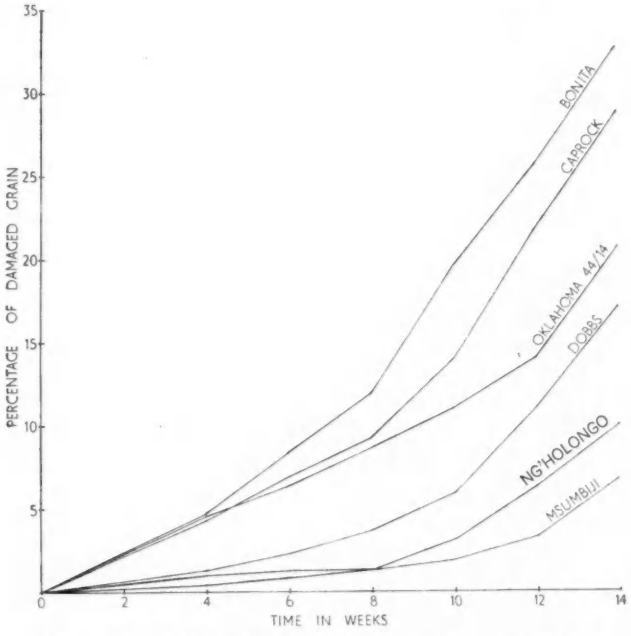

FIG. 1. Rates of weevil damage for 6 varieties from Table 2.

The Relationship between Rate of Weevil Damage and some Sorghum Grain Characters

The sorghum endosperm may be divided into two parts, an outer shell of corneous endosperm, and a central core of mealy endosperm. There is great variability between sorghum varieties, from soft grains lacking the corneous shell to hard, brittle grains with an endosperm which is wholly corneous. Intermediate forms show varying proportions of corneous shell, and in some the shell is fairly thick at the sides

of the grain, but thin or lacking below the style scar. The proportions of the two endosperm types are reasonably consistent within sorghum varieties, although there is some variation from season to season. There are differences in appearance between the corneous shells of various

TABLE 2. *Storage Test on Seventeen Sorghum Varieties. Period of test 14 weeks.* (*23.8.–29.11.52.*) *Ten Replications*

Variety	*Mean percentage loss after 14 weeks* y	*Thickness of corneous endosperm shell* ($1 = \frac{1}{12}$ *mm.*) l	*Volume of 1,000 grains* (*c.c.*) v	*Estimate of percentage corneous material in endosperm*
Msumbiji	6·8	10·5	18·5	90
Wiru	8·1	10·4	17·0	90
Belko	8·5	10·4	18·0	90
Ng'holongo	10·0	6·7	20·0	70
Kabili	12·3	6·9	21·5	70
Mwemba Mwitune	16·4	9·0	24·5	80
Dobbs	17·1	2·1	21·5	30
Kano	18·2	2·3	23·5	30
Korgi	18·9	7·9	55·5	60
Oklahoma 44/14	20·7	5·1	21·5	55
2/1/8	21·4	8·9	36·5	75
Martin	21·6	4·2	23·5	50
B.C. 27 White	21·8	3·5	20·0	45
Early Hegari	26·1	3·3	21·5	40
S.B. 85	28·3	2·8	25·0	35
Caprock	28·8	3·0	25·5	35
Bonita	32·7	2·2	21·5	30
Sig. diff. $P = 0{\cdot}05$	5·0			
Sig. diff. $P = 0{\cdot}01$	6·5			

varieties, some seeming more compacted and harder than others, but no allowance has been made for this.

It seemed that sorghum varieties reputed by the local people to store well had a relatively thick corneous shell, and this character was chosen for investigation, measurements being made by reflected light on halved grains, along the diameter of the grain below the style scar. Other characters studied were grain density, grain volume, and hardness. The latter proved too difficult to measure with the facilities available, and was discarded.

Storage tests were done in the usual manner, with 17 varieties in 10 replications (1952, Table 2), and 72 varieties in 6 replications (1953, Table 3). Analyses of the actual data are given: use of the angular transformation somewhat improved the precision of the comparisons, but did not otherwise give results different from those obtained from the straightforward analysis.

Corneous shell. The figures in column 3 are means of measurements on 50 grains of each variety, in eye-piece units of $\frac{1}{12}$ mm.

Density. Ten estimations on fresh 200-grain samples of each variety in the tests were made. Figures ranged from 1·24 to 1·37 in the varieties of Table 2, and from 1·10 to 1·41 in the varieties of Table 3.

In both cases the regressions of corneous-shell thickness and density were significant at P = 0·01, the grains with the thickest shells having the greatest density. In view of this association it was not possible to disentangle the relationship between density and damaged grain from that between shell thickness and damaged grain. Density figures have therefore been omitted from the tables.

Grain volume. Figures are taken from the weight of water displaced in the density measurements.

The contrast between corneous (shell thickness > 6 units) and non-corneous (shell thickness < 6 units) varieties is significant, the corneous having suffered less damage, as the following extract from the analysis as randomized blocks shows:

	d.f.	s.s.	m.s.	
Contrast, corneous v. non-corneous	1	5,239	5,239	F = 167·5
Error	144	4,502	31·3	(F from table ≏ 11 at P = 0·001).

Using y for the mean percentage of damaged grain, v for grain volume, and l for layer thickness, the following regressions are obtained:

	Regression	*Standard error*	*t (observed)*	*t (table)*
b_{yl} . . .	−1·842	±0·412	4·471	4·073 (P = 0·001)
$b_{yv \cdot l}$ . . .	+0·252	±0·135	1·867	1·753 (P = 0·1)
$b_{yl \cdot v}$ . . .	−1·908	±0·383	4·982	4·073 (P = 0·001)

There appears to be an association between a low percentage of weevil damage and a thick layer in the endosperm, which is slightly improved when allowance is made for grain volume. There is also a suggestion that varieties with small grains suffer less damage than varieties with large grains.

Layer thickness is not a measure of the proportion of corneous material in the endosperm for comparisons of grains with very different volumes. The last column in Table 2 gives a crude estimate of the amount of corneous material in the endosperm, making the assumptions that the grains are spherical, and that the embryo occupies a sector. As an absolute measure it means little, but may be of use in comparing the proportion of corneous shell to mealy core in the different varieties. Dobbs and Kano (both very similar varieties, differing mainly in the amount of pigment in the grain) are anomalous in column 5, but on the whole it seems that varieties with largely corneous endosperms showed the greatest weevil resistance.

Again (see Table 3), the contrast between corneous (shell thickness > 6 units) and non-corneous (shell thickness < 6 units) varieties is marked, as the following extract from the analysis as randomized blocks shows:

	d.f.	s.s.	m.s.	
Contrast, corneous v. non-corneous .	1	12,598	12,598	F = 160.
Error	355	28,004	78·9	(F from table ≏ 11 at P = 0·001).

The regression of layer thickness on volume is just significant at P = 0·05, small grains tending to have thicker layers, so that it is not possible to disentangle the volume and layer-thickness effects properly.

TABLE 3. *Storage Test on Seventy-two Sorghum Varieties. Period of test 14 weeks. (17.8.–27.11.53.) Six Replications*

Percentage loss	*Number in class*	*Mean corneous shell thickness of class* ($1 = \frac{1}{4}$ *mm.*) l	*Mean grain volume of class, 1,000 grains. (c.c.)* v	*Estimated mean percentage of corneous material in endosperm*	*Varieties in class*
5–7	2	10·0	14·9	90	
8–10	1	7·5	16·5	80	
11–13	7	8·5	17·6	80	Wiru, Msumbiji
14–16	8	6·2	20·3	65	Kano, Ng'holongo
17–19	6	4·3	22·7	45	
20–22	7	6·9	25·2	70	Dobbs, Mwemba Mwitune
23–25	9	3·7	25·2	40	
26–28	9	3·9	24·5	45	
29–31	3	2·5	26·0	30	B.C. 27 White, P. 41
32–34	5	6·0	25·2	60	Early Hegari, S.B. 85
35–37	4	2·4	27·7	30	
38–40	3	3·0	25·8	35	Bonita
41–43	4	4·1	34·1	45	Korgi
44–46	2	2·7	23·0	35	
47–49	1	2·0	21·8	25	
50–52	1	1·0	27·2	15	
	72				

Sig. diff. (percentage loss): 10·1, P = 0·05; 13·2, P = 0·01.

Using the same notation as before, the following regressions are obtained from the data:

	Regression	*Standard error*	*t (observed)*	*t (table)*
b_{yl} . . .	−2·207	±0·380	5·808	3·460 (P = 0·001)
$b_{yv.l}$ . . .	+0·722	±0·150	4·815	
$b_{yl.v}$ . . .	−1·840	±0·339	5·428	

The association between a thick endosperm layer and a low percentage of damaged grain is good, but when grain volume is allowed for, this association is not improved. The principal difference between these figures and those from Table 2 is the association between high weevil resistance and low grain volume, which is here significant at P = 0·001.

The proportion of corneous material in the endosperm (column 5) is more variable than in the previous test, but again those with the highest percentage of corneous material suffered least weevil damage.

The characters examined do not account for all the weevil resistance of all the varieties tested, but much of the weevil resistance in many of the varieties tested can be associated with a high proportion of corneous shell in the endosperm, and with small grain size.

Both of these characters are easily judged in the field, and many hundreds of sorghum panicles can be assessed quickly, so that these characters may be of real value in breeding grain-weevil-resistant sorghum varieties.

Selection for Grain-weevil-resistant Sorghums in the Field

In 1950 over 1,000 sorghum heads were selected from various early-maturing bulks, choosing heads with a thick corneous shell in the endosperm of the grain, by biting ripe grains in the field, regardless of grain

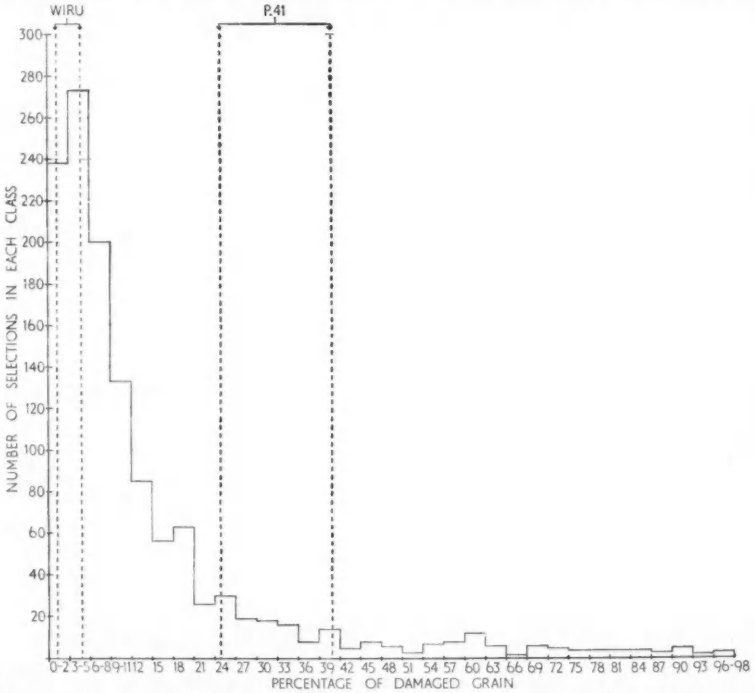

FIG. 2. Frequency distribution of damaged grain in 1,276 sorghum selections in storage tests, with fiducial limits (P = 0·01) of Wiru and P. 41 controls.

size. The plants chosen were in the large majority of cases markedly off-type, almost certainly segregates from natural out-crosses. One hundred grains from each panicle were put into storage tests: there was too little material to allow of replication, but the 1,276 selections were divided among eleven of the usual 4-gallon petrol tins containing weevilly grain, and in each tin two bags of a weevil-resistant variety (Wiru) and two bags of a weevil-susceptible variety (P. 41) were included as controls. The distribution of the percentage of damaged grains in the tests of these selections, together with the fiducial limits (P = 0·01) for the controls, is given in Fig. 2.

A high proportion of the selections with a thick corneous shell in the endosperm show weevil resistance. These selections were grown out in progeny rows, and fresh selections taken from them. A very large number showed undesirable characters such as tight glumes and very small panicles, so the standard of selection for thickness of corneous shell was relaxed, in order to include enough plants with reasonable

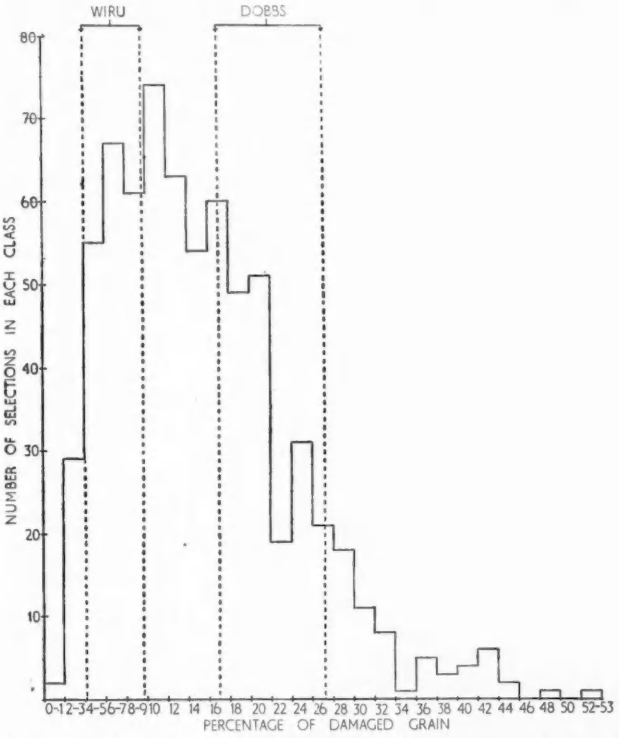

FIG. 3. Frequency distribution of damaged grain in 696 sorghum selections in storage tests, with fiducial limits (P = 0·01) of Wiru and Dobbs controls.

field characters. Grains from the 696 fresh selections were put into another test, using seven tins, with Wiru and Dobbs as controls (Fig. 3).

The distribution is less skew than that of the original selections in Fig. 2, but the relaxing of the selection standard could account for this.

It would seem that selecting for grains with corneous endosperms is a practicable method for use in breeding grain-weevil-resistant sorghum varieties.

Discussion

The local people are well aware that different sorghum varieties have differing keeping qualities. Varieties such as Wiru are said to remain in

good condition for up to five years when stored in grain baskets smeared with dung. Other varieties, such as Bukura Mahemba, will remain fit for food for barely one year under similar conditions: introduced early varieties like Dobbs or P. 41 keep sound for only a few months. Differences in weevil resistance in sorghum have been reported from the Belgian Congo [1, 2].

There is a need to develop early-maturing sorghums with weevil-resistant grains. The method described for assessing weevil resistance is simple, and gives consistent results from season to season: the results obtained tally with local opinion of the keeping qualities of the varieties used.

It is surprising to find that grains of certain sorghum varieties succumb relatively slowly to weevil attack under the conditions of these tests. The population of weevil in the sorghum bulk surrounding the grain under test is very large, and it seems certain that these varieties must have some characteristic which discourages weevil attack. The differences between the rates of weevil damage in bulks of the sorghum varieties, when the weevil numbers are building up within the bulks themselves, may be expected to be much greater than those obtained in these tests. Evidence of this will be given in a subsequent paper.

The next step—finding an association between obvious grain characters and weevil resistance—has been moderately successful. Grains which are largely corneous have been shown to be damaged more slowly in these tests than grains with a mealy endosperm: and small grains keep better than large ones. A sufficient proportion of grain-weevil-resistant plants can be identified in the field, using these characters, to make breeding for weevil resistance practicable: the breeding of grain-weevil-resistant, early-maturing sorghum varieties will be described in a subsequent paper.

No evidence is offered on the nature of weevil resistance, and the presence of a thick corneous shell may itself be linked with some other character which confers resistance. Moisture contents, and crude-protein estimations ($N \times 6{\cdot}25$) on duplicate samples of forty-nine varieties included in the test in Table 3 were kindly done by the Government Chemist, Dar es Salaam. There were no differences between the mean moisture contents (10·80 per cent. and 10·86 per cent.) and mean protein contents (10·15 per cent. and 10·20 per cent.), on a fresh-weight basis, between twenty-six varieties with thick corneous shells, and twenty-three varieties with thin corneous shells. Nevertheless, it is quite possible that a hard corneous endosperm is less suited to the weevil's needs than a soft mealy one, and these insects hardly ever attack the grain via the embryo. Weevil resistance is only a slower rate of damage, and does not do away with the need for proper handling of bulk grain, but corneous sorghum grains arrive at the bulk stores in better condition than soft, mealy ones, after the journey from the peasant producer through various small traders. Weevil-resistant grain will also last in sound condition for a longer time in the peasant's own food store.

It is emphasized that the only aspect of keeping quality considered here is weevil resistance: some weevil-resistant grains may succumb

quickly to grain moth, and a bad attack of grain moulds may much reduce the keeping quality of the grain.

The progress of the work described in this paper has been reported elsewhere [3].

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(*Received 16 March 1956*)

APPENDIX

Sorghum Varieties Mentioned in the Text

Wiru. A group of tall, late (5–6 months) indigenous sorghums, widely grown in the Lake Province, and maintained by the local people as named 'varieties', separated on small differences in length of maturity, hairiness of glumes, awn length and height. Grains dull white, with thick corneous endosperm shell. Regarded as one of the best storing varieties in the Lake Province by local people.

Msumbiji. Tall, late (6 months), very lax panicle, grain cream in colour and shiny. At one time grown extensively in the southern coastal area of Tanganyika, and often taken back to Arabia by dhow traders. Reputed to store very well even under humid coastal conditions.

Ng'holongo. Indigenous and fairly widespread in the Territory. Tall, late (6 months), goose-necked, grain white with a corneous layer. Considered to store well.

Kabili. As for Ng'holongo, but twin grains in all spikelets.

Belko. From the Gold Coast. Tall, late maturing (5 months), white grain, reputed to store well in West Africa.

Mwemba Mwitune. From Kenya. Tall, late (5–6 months), grain resembling that of Wiru.

Dobbs. Early maturing (4 months), dwarf. Originally imported from Kenya, tried on a wide scale in Tanganyika, and regarded by local people as a poor storer. Brown, rather bitter grain.

Kano. As for Dobbs, but grain dark red. Not distributed on any scale in Tanganyika.

P. 41. Hegari type bred in Swaziland. Early maturing (3 months), double dwarf, tried in parts of Tanganyika and regarded as a very poor storer. White grain with dark nucellar layer.

B.C. 27 White. A selection taken about 1942 out of a red-grained introduction, 27 U.T., from the Belgian Congo. Hegari type, dwarf, maturing about 3½ months, grain white with dark nucellar layer.

S.B. 85. A selection from B.C. 27 White. Grain similar.

Korgi. From the Sudan. Late maturing (5 months). Goose-necked, stem long but very curved in growth. Unusually large grains, having yellow pigment in the outer endosperm shell.

2/1/8. From Nigeria, dwarf, late maturing (5 months), grains large with yellow endosperm layer.

Oklahoma 44/14, Martin, Caprock, Early Hegari, Bonita, Shallus. Combine-type sorghums bred by American workers.

LIVE-WEIGHT CHANGES OF CATTLE IN EAST AFRICA

M. H. FRENCH AND H. P. LEDGER
(*Joint Animal Industry Division, E.A.A.F.R.O. and E.A.V.R.O.*)

Summary

1. Details are given of the differential responses of 2-tooth and 4-tooth grade oxen and full-mouthed Zebu steers to productive nutritional planes following pre-experimental treatments on sub-maintenance, maintenance, and super-maintenance diets.

2. Considerable diversity was encountered in the average results from groups of five animals, all of which had been herded together for 6 months prior to the pre-experimental period. It is suggested that larger groups should be used for experimental studies in East Africa.

3. In choosing groups of oxen for grazing studies, care must be exercised to avoid the formation of groups which have been on different nutritional levels prior to the experimental period.

4. The bearing of the results obtained on management practice and breeding work in East Africa is discussed.

ATTEMPTS to evaluate pasture productivity have occupied numerous workers in many lands and the large volume of published information reflects the inherent difficulties in what, at first sight, might appear a straightforward problem. Quite apart from the difficulties encountered in estimating herbage yields and their nutrient contents, a voluminous literature is concerned with the correlation of grassland output with live-weight maintenance and the productivity of the grazing animals. In view of the fundamental dependence of local herbivora on grassland and the general lack of information concerning the grazing values of East African herbage, experiments have been inaugurated at Muguga, Kenya, to determine the practical possibilities and the inherent difficulties associated with grazing trials.

Animal responses to pasturage depend on the quantity and quality of the herbage available. They also vary not only with the type of livestock employed but also with the breed, age, weight, stage of maturity, the metabolic efficiency, the adaptability to environmental conditions, as well as on the nature and the level of the productivity. Unfortunately variations occur in individual responses to the consumption of a given quantity of grass or of a diet containing grass supplemented with other feedingstuffs, even when all the experimental animals have been fed and managed similarly prior to a particular feeding trial.

In common with those in many other parts of the world, native-owned cattle in Kenya derive their sustenance very largely from the natural grazings and the latter are considerably affected in nature and quality by the markedly seasonal distribution of rain. The rapid growth of herbage following the onset of the rainy season provides more fodder than the animals can deal with adequately so that, over large areas, the grasses reach maturity by the time the seasonal rains have ceased. The stock continue to graze this mature herbage and, as this decreases in quantity and quality, the rate of live-weight increase is slowed down.

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Ultimately a stage is reached when insufficient fodder can be collected daily by the animals to permit the maintenance of live-weight, and weight losses then occur. Quite obviously, these seasonal live-weight oscillations could be eliminated by the adoption of recognized methods of conservation, but the prospect of these practices being put into operation over a wide area is extremely speculative; they will probably be applied first in the restricted, more intensive zones. The following studies therefore have little likelihood of influencing the management practices of the millions of livestock living a nomadic existence in the arid and semi-arid areas and have little bearing on millions of other cattle seasonally subsisting under the shifting-cultivation systems of their owners. A start must, however, be made towards improving the rates of development of stock in the less-extensive agricultural regions and, although designed for another purpose, the present studies have an important bearing on livestock management practices in the dry season.

Experimental Programme

It is true that such factors as the stage of maturity and the type or breed of an animal have been recognized as being of importance in the assessment of grazing values, but often little attention has been paid to the possible consequences of the pre-experimental treatments of the animals, in their responses during the experimental period. The object of the present experiments was therefore to collect information on the responses, to different levels of feeding, when stock had previously been maintained on sub-maintenance, maintenance, or productive rations, in the hope that these responses would indicate factors to be avoided when conducting grazing trials. Except in the more favoured regions, such trials often commence with animals which have but recently come through the dry season. Consequently the animals are often in a recovery stage succeeding a period of sub-maintenance due to the seasonal shortage of grazing and to subsistence on sparse and desiccated herbage of low feeding value. It is important to know what variations in response are likely as a result of previous planes of nutrition particularly since a common system, in East Africa, is to evaluate pastures and individual grasses by the live-weight changes in animals grazing thereon during the wet season and during part of the subsequent dry weather until the herbage has been removed.

Experimental Results

To illustrate the types of response commonly encountered, Fig. 1 shows the live-weight changes in two groups of six Zebu oxen turned out to graze at the beginning of the 1938 wet season. The animals were all full-mouthed and of comparable weights. From the results it would be reasonable to deduce that the herbage fed to Group A was superior, either in quantity or quality, to that fed to Group B. Actually both groups grazed together in the same field for the same length of time and were under identical management conditions. The two groups were first thus put together on the fourteenth day, after having been previously under different conditions of feeding and management. Group A had

been losing weight for at least 8 weeks prior to the commencement of Fig. 1, whereas group B had been on approximately a maintenance ration during this pre-period. The greater live-weight response of Group A is partly the result of an increase in the weight of the contents of the alimentary tract and partly the consequence of a greater appetite following a period of under-nutrition, combined with a tendency to recuperate

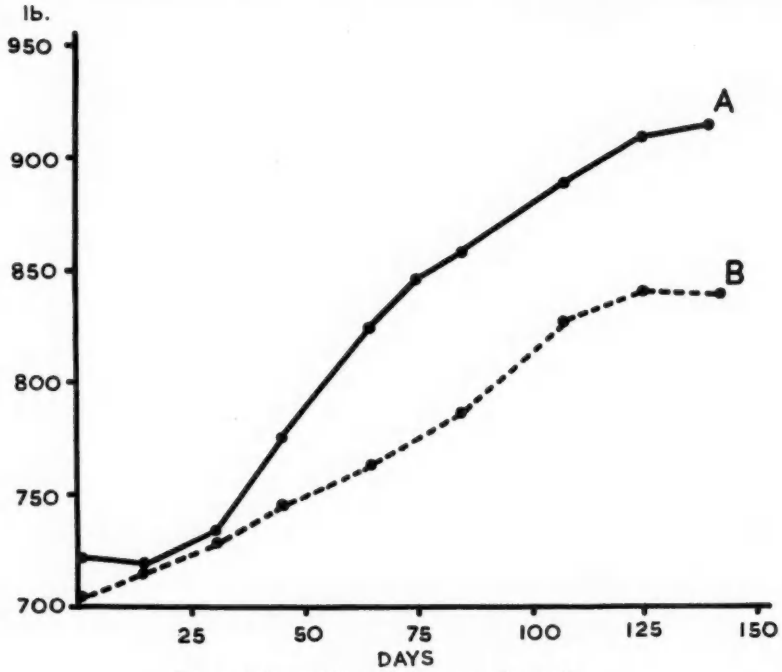

FIG. 1. Live-weights of Zebu oxen in 1938.

tissue losses sustained during that period. The differential responses on green grass emphasize the need for care in designing experimental groups if erroneous conclusions are to be avoided.

During the 1953–4 dry season, a further study of this problem was made using groups of 2-tooth and 4-tooth grade European × Zebu oxen and a group of full-mouthed Zebu steers. Fifteen animals were used for each group, divided into three lots of five. To avoid complications of the type illustrated in Fig. 1, the animals had all been running together for 6 months prior to the commencement of the trials. Within each group the aim was to run one lot (Y) on a maintenance diet, another lot (Z) under sub-maintenance conditions, and the third lot (X) on a ration which provided more than maintenance needs. This was achieved by allowing lot Y to graze all day and to be herded in a kraal at night. Lot X grazed with lot Y in the daytime but received oat hay and maize

silage at night. Lot Z were kept in a restricted area without grazing during the daytime, when they were fed a restricted quantity of oat hay such as would cause a decrease in live-weight.

After 4 weeks on these rations, adjustments had to be made to the consumption of the steers on the sub-maintenance diet in order to accelerate the live-weight losses. The animals in each sub-group continued on their various diets for a further 6 weeks, or a total of 10 weeks

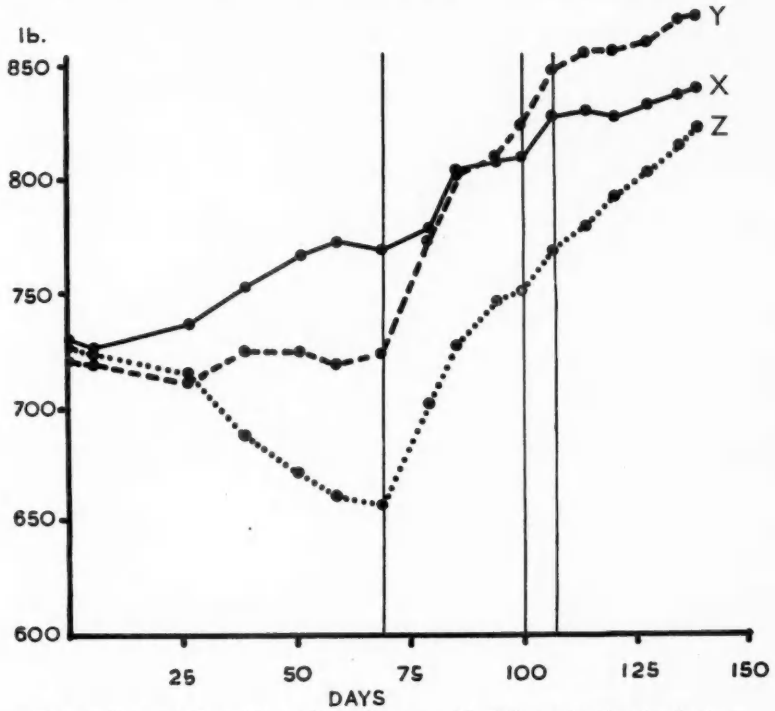

FIG. 2. Live-weights of 2-tooth grade oxen with different levels of rationing.

(Period *a*). All lots were then put on to a ration which permitted a fairly rapid live-weight increase of lot X. This consisted of grazing *ad lib.* on dry pastures during the daytime, supplemented at night in their kraals with 6 lb. of maize silage and 4 lb. of concentrates for each animal (Period *b*). The percentage composition of the concentrate mixture was 49 per cent. cottonseed cake, 49 per cent. maize meal, $\frac{3}{4}$ per cent. bone meal, $\frac{1}{2}$ per cent. lime, $\frac{1}{8}$ per cent. copper sulphate, $\frac{1}{8}$ per cent. cobalt sulphate, and $\frac{1}{4}$ per cent. ferrous sulphate.

The average live-weight changes secured with the groups of 2-tooth and 4-tooth grade oxen and the full-mouthed Zebu steers are shown respectively for these first two periods (*a* and *b*) in Figs. 2, 3, and 4, together with the further live-weight responses in the next two periods.

In the third period (*c*) the animals were allowed to graze on dried-up pasturage during the day but received double the amounts of silage and concentrates fed in the second period. This double ration was fed for only 7 days and the animals were then turned on to a new paddock containing adequate but dry grass. No supplementary feeding was given

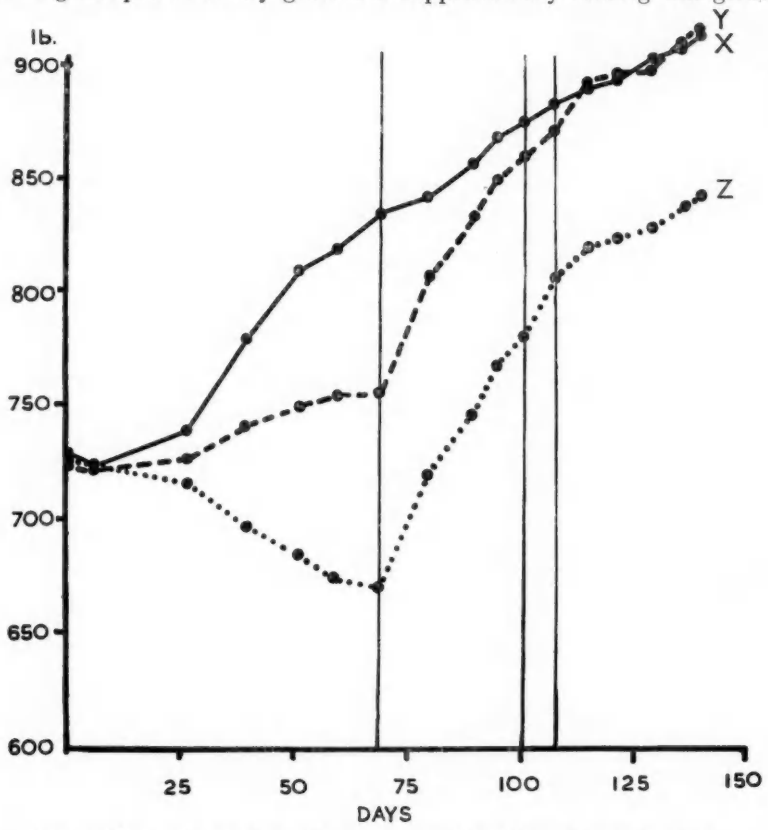

FIG. 3. Live-weights of 4-tooth grade oxen with different levels of rationing.

during this last period of 21 days (*d*) and, in consequence, the previous rates of live-weight increase were reduced in the grade animals and the Zebu stock remained close to maintenance.

Table 1 summarizes the average live-weight changes in the respective periods. In every case the average weights were determined, after watering, on three consecutive days immediately after leaving the night kraals and before going out to graze. The first point to merit attention is the fact that the 4-tooth grade animals apparently made better use of their food supplies, at all levels of feeding, than either the 2-tooth grades or the Zebu animals in the pre-experimental periods. In fact an analysis of

variance of the average daily live-weight changes during the first period (*a*) shows that the 4-tooth animals differed significantly (at the $P = 0{\cdot}05$ level) from the 2-tooth grade and Zebu animals. As would be expected, the average daily live-weight variations were very significantly different (at the $P = 0{\cdot}01$ level) at the different planes of nutrition.

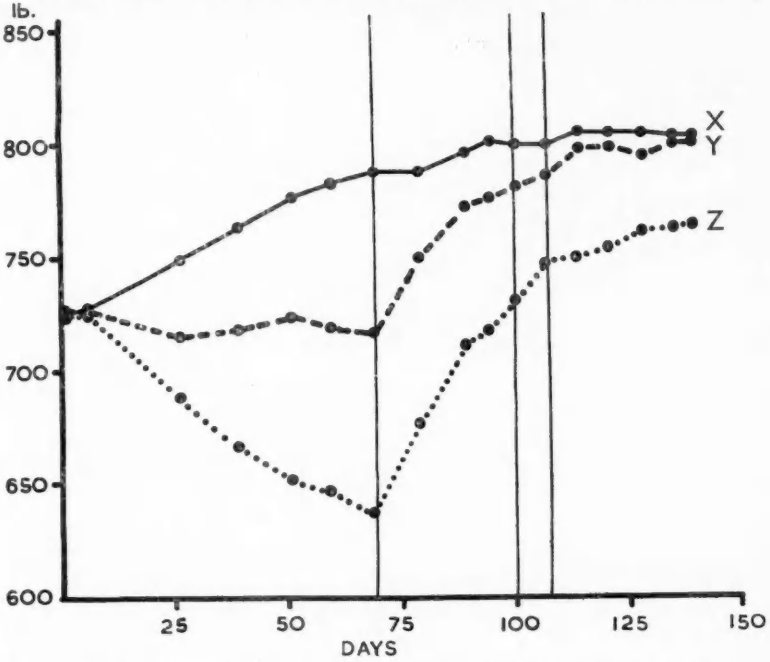

FIG. 4. Live-weights of full-mouthed Zebu oxen with different levels of rationing.

TABLE 1. *Summary of Average Live-weight Changes of Oxen, lb.*

Level of rationing during Period a	*Period*	*a*	*b*	*c*	*d*	*Total*
	No. days	*69*	*31*	*7*	*31*	*138*
Super-maintenance	2-T grades	+40	+41	+18	+14	+113
	4-T grades	+106	+40	+8	+32	+186
	8-T Zebus	+63	+12	+0	+4	+79
Maintenance	2-T grades	+3	+102	+23	+26	+154
	4-T grades	+29	+108	+11	+45	+193
	8-T Zebus	−10	+64	+6	+15	+75
Sub-maintenance	2-T grades	−70	+94	+19	+54	+97
	4-T grades	−55	+61	+25	+37	+68
	8-T Zebus	−89	+94	+18	+16	+39

An analysis of variance of the live-weight changes during periods *b*

and *c*, when the animals were fed silage and concentrates in addition to their grazing, indicates that the responses of the grade animals differed significantly (at the P = 0·05 level) from the reactions of the older Zebu cattle. If the changes during the last period (*d*) are analysed, when the animals were on grazing only, no significance is found for the effects of the pre-experimental ration or between types of animals. In the latter case, however, the 4-tooth grades gained more than the other two groups but the difference did not reach the P = 0·05 significance level. If the responses in periods *b*, *c*, and *d* are combined, analysis shows, as might be expected, that the variance due to the different pre-treatments was significantly less (at the P = 0·05 level) for the lots which had been on the super-maintenance level of feeding in period *a* than for the groups which had then been on maintenance or sub-maintenance diets. Although the grade animals made larger live-weight gains than the Zebus, the differences did not reach the P = 0·05 significance level. Similarly, if the total live-weight changes from the beginning of the pre-experimental period *a* until the end of period *d* are examined, no differences between animals or the pre-experimental diets are significant. In other words, cattle have either a remarkable ability to recuperate from temporary periods on maintenance or sub-maintenance diets or the live-weight losses during such periods are appreciably exaggerated by changes in the amount of their alimentary contents.

Another point which develops from these results is that even with animals which had been managed together for 6 months prior to the beginning of the pre-experimental periods, considerable diversity in the average responses from lots of five animals of different ages were apparent. Even within a given age group the variation between individuals is still appreciable and it is obvious that with groups of five animals it would not be easy to demonstrate significant differences in the grazing values of grasses unless their yields and nutritive values were widely different. It would almost certainly be desirable to use larger numbers of animals. It is equally apparent that in choosing groups of oxen for grazing trials, care must be taken to avoid the formation of groups which have been on different levels of nutrition prior to the commencement of the trials. The results of period *d* indicate that even for oxen which have been on such widely different planes of nutrition, as super-maintenance, maintenance, and sub-maintenance, a preliminary period of 38 days on good productive rations eliminates significant differences between responses of groups of these animals when they are subsequently grazing together on the same field. The feeding of productive rations is probably the most important factor in this pre-experimental conditioning period, but the results suggest that this preliminary period on productive rations could, with advantage, be extended in order adequately to avoid disturbances in the experimental periods due to the consequences of the nutritional levels which were operating prior to the feeding of the productive ration in the pre-experimental period. The implications are obvious and indicate the need for more extensive study if the results of East African grazing trials, assessed by live-weight responses, are to be of statistical significance.

Discussion

Turning now to the implications of these studies in management practice, it is obvious, from the analysis of variance of the live-weight changes over the whole 138 days, that oxen have a remarkable ability to recover from temporary periods of inanition. The differences between live-weight responses over the combined preliminary and the subsequent three experimental periods did not reach the $P = 0{\cdot}05$ level of significance either between the different animal groups (lots X, Y, and Z) or due to the preliminary 69 days of period *a* on super-maintenance, maintenance, and sub-maintenance feeding. On the other hand, both from the graphs and the appearance of the animals, the two former lots fared better than those which were subjected to a period of subsistence. As would be expected, once the animals had been subjected to 69 days on the three different planes of nutrition, the live-weight responses in period *b*, periods *b* and *c*, and periods *b*, *c*, and *d*, when all were on the same ration, differed at the $P = 0{\cdot}05$ significance level, between animals which had been on the super-maintenance level and those which had been subjected to maintenance or sub-maintenance conditions.

The fact that no apparent benefit was derived from super-maintenance supplementary feeding suggests that, for East African conditions, the aim in the dry season should be to maintain weight but not to attempt to augment it if this can be achieved only by the purchase of supplementary foodstuffs.

Equally too, this finding forms an important pointer for animal-breeding investigations. In the temperate areas, breeding problems are generally studied on animals living on good nutritional planes in order that breeding effects shall not be conditioned by inadequate nutrition. In East Africa, the general level of African-owned stock involves a period of subsistence and to select improved genetic types on a plane of feeding and management vastly superior to that which is likely to be achieved in a reasonable period, is to court disaster. Improved genetic strains evolved in such a superior nutritional environment will automatically be at a disadvantage when subjected to significantly poorer feeding conditions and the objective should be to evolve superior genotypes in an environment which is reasonably related to African possibilities. Since the achievement of maintenance instead of subsistence conditions in the dry season is more than can be reasonably expected for by far the greater majority of African-owned cattle, it would seem desirable for genetic studies in the reasonably near future to be conducted under no higher nutritional levels than maintenance. Admittedly this level of nutrition applies specifically to African-owned herds which constitute some 95 per cent. of the cattle in East Africa and a higher environmental plane would be justifiable for the under-five percentage of the cattle population in European hands.

It might be doubted whether attempts to secure genetic improvement are justified when, for part of the year, the animals are restricted to maintenance conditions. That this is so is obvious when it is remembered that subsistence, for varying periods of the year, is one of the most

potent agents militating against African livestock improvement and that it is usually the most productive animals which are most severely discriminated against during such subsistence periods. The gap between present nutritional levels for millions of African-owned stock and the conditions permitting maintenance during the worst periods of the year, is so great that stock selected in a permanently productive environment would be so out of harmony with current African practice that they could not be redistributed to unimproved zones without the serious risk of their breaking down.

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THE EFFECT OF RATE AND TIME OF APPLICATION OF NITROGEN ON THE YIELD OF WINTER WHEAT

G. A. BLACKETT

(*North of Scotland College of Agriculture, Aberdeen*)

Summary

Nitrogen, as Nitro-chalk, was applied to Cappelle wheat following potatoes, at 30 lb. per acre, at seeding time, as a late March top-dressing and as a late May dressing. Treatments were also tested in which the nitrogen was applied at either 15 lb. per acre or 30 lb. per acre at each of these dates.

Spring dressings of nitrogen at 30 lb. per acre gave grain responses ranging from 10·22 cwt. as a late May dressing to 11·58 cwt. where given in two 15-lb. doses in late March and late May. Increasing the nitrogen applications to 30 lb. per acre on each of these dates resulted in a 21·40 cwt. grain response.

Straw-weight increases were greatly affected by the time of applying nitrogen and the quantity given. Nitrogen applied at 30 lb. per acre in late March produced 17·12 cwt. more straw per acre than a similar dressing in late May.

But no positive response was obtained in either grain or straw to nitrogen, as Nitro-chalk, applied to the seed-bed.

PUBLISHED work on the effect of applying nitrogenous fertilizers to winter wheat reveals a lack of factual information on this particular subject for the north of Scotland region; this deficit may be largely ascribed to the insignificant role of wheat in the past in the farm economy of this area, which has deterred critical husbandry investigations of the crop. However, crop statistics for the region show that the area under wheat is increasing. The crop returns for Aberdeenshire, for example, reveal that the acreage of wheat is now almost four times what it was three years ago: and that while the wheat acreage recorded for the 1954–5 cropping year represented only 0·6 per cent. of the county's cereal acreage, there is every likelihood of a further increase in 1955–6.

Recent appreciation of the high-yielding capabilities of some of the newly introduced short-strawed wheat varieties has undoubtedly encouraged more growers to re-examine the economic possibilities of the crop. In response to this lively interest an investigation was conducted to determine the effect of Nitro-chalk applied at varying rates and at different growth stages, to winter wheat grown in the northern counties of Scotland.

Nitrogen Treatments and Experimental Procedure

Following early potatoes, Cappelle wheat was sown in the Woodlands Field at Craibstone, the experimental farm of the North of Scotland College of Agriculture, in the late autumn of 1954 at a seeding of three bushels to the acre. The soil, a medium loam of granitic origin, received as a basal manurial treatment 5 cwt. per acre potassic superphosphate, broadcast. The experimental dressings to test the effect of applying

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nitrogen, as Nitro-chalk, at different levels and at different growth periods of the crop were as follows:

0. *Control.* Basal fertilizer only.
1. 30 lb. N at time of sowing.
2. 30 lb. N late March.
3. 30 lb. N late May.
4. 15 lb. N late March and 15 lb. N late May.
5. 30 lb. N late March and 30 lb. N late May.

The plots, which were 1/242 acre in size, consisted of eight rows at 8 in. spacing and were arranged in randomized blocks with four replications.

Counts of ear-bearing plants were made prior to harvesting the plots, in the centre two drills; ten 1 ft. counts were made in each row. The figures given in Table 1 for ear-bearing plants represent the mean values obtained for each treatment, calculated on an acreage basis.

The plots were cut by scythe and the stooked sheaves were stored in a well-ventilated shed. Grain samples were taken at threshing for moisture determination. Estimations of nitrogen and one-thousand-corn weights were made on oven-dried grain.

Results

The main effects of the various nitrogen treatments on the grain and straw are set out in Tables 1 and 2.

Grain yield. After statistical analysis the following conclusions may safely be drawn from the data presented in a condensed form in Tables 1 and 2.

TABLE 1. *The Effect on Grain and Straw of Cappelle Wheat of applying Nitro-chalk at Varying Rates and at Different Growth Stages*

Treatment	GRAIN *cwt. per acre*	*Ear-bearing plants 000's*	*1,000-corn wt. gm.*	N %	*Crude protein in grain cwt. per acre*	STRAW *cwt. per acre*	*Straw height in.*
0	20·77	632	55·63	1·37	1·618	25·82	31·00
1	21·09	649	55·02	1·36	1·641	25·55	30·67
2	31·57	1,026	55·83	1·27	2·284	49·99	36·78
3	30·99	882	54·36	1·33	2·320	32·87	33·00
4	32·35	968	54·77	1·21	2·232	42·68	36·12
5	42·17	1,280	54·93	1·34	3·203	51·24	38·08
S.E.±	0·942	45·46	0·46	0·028	0·105	1·028	0·353

TABLE 2. *Increases in Grain due to Spring Nitrogen Applications*

Nitrogen applied	*Date of application*	*Increase in yield due to nitrogen*
lb. per acre		cwt. per acre
30	March	10·80
30	May	10·22
30 (15 early, 15 late)	March, May	11·58
60 (30 early, 30 late)	March, May	21·40

The responses in yields of grain to all the dressings of nitrogen given in spring were highly significant as shown by the following three examples:

30 lb. N applied in late March gave a 52 per cent. higher yield than the control;

30 lb. N applied in late May gave a 49 per cent. higher yield than the control;

60 lb. N (30 lb. N applied at each of the above dates) gave a 103 per cent. higher yield than the control.

In regard to the quantity of fertilizer applied, comparing the increases in grain yield at the 30 lb. and 60 lb. nitrogen levels, the response to the higher level of nitrogen showed little manifestation of the law of diminishing returns. The response to the second 30 lb. of the composite dose of 60 lb. nitrogen, above that given by 30 lb. in two 15-lb. doses in late March and late May, 9·82 cwt. was highly significant ($P = 0{\cdot}01$) and almost as great as that obtained by the first composite dose, 11·58 cwt.

In regard to the date of application of the fertilizer the data significantly indicate that nitrogen given at seeding was ineffective in producing higher grain yields. The application of 30 lb. of nitrogen, as Nitro-chalk, to the seed-bed gave a yield only 0·32 cwt. higher than the control, an insignificant difference. All spring nitrogen dressings, on the other hand, were highly effective in increasing grain yields. Whilst indications were obtained that the application of the 30-lb. nitrogen dressing tended to be more effective when applied in late March than when applied in May, the resulting difference in grain yield, 0·58 cwt. is not statistically significant. Similarly, the subdivision of this dressing into two applications, given at these two dates, gave a higher yield of grain, but this difference also was not statistically significant.

Ear-bearing plants. All spring dressings increased the number of ear-bearing plants at harvest. For the 30-lb. nitrogen rate, i.e. treatments 2, 3, and 4, the largest increase resulted from the late March treatment; the late May dressing was the least effective. The difference between these two treatments was significant at the $P = 0{\cdot}05$ level.

The 60-lb. nitrogen rate, i.e. treatment 5, gave the largest increase, significantly higher than the best of the 30-lb. nitrogen treatments.

The correlation coefficient number between ear-bearing plants and grain yield was naturally highly significant.

1,000-Corn weight. The values were very similar for all treatments, and in no case did the differences approach statistical significance.

Nitrogen content. The percentage nitrogen content of grain was not increased by any of the nitrogen treatments. The tendency was rather to depress nitrogen content, though there were marked differences between the treatments.

Nitrogen at 30 lb. per acre in late May had the least depressive effect. The split nitrogen application in two dressings each of 15 lb. per acre resulted in a highly significantly ($P = 0{\cdot}01$) lower nitrogen content than that obtained for all other treatments, except the 30 lb. March dressing, and even for this the difference reached the $P = 0{\cdot}05$ level of significance.

This latter treatment (2) gave a significantly lower nitrogen content than the no-nitrogen treatment (0) and nitrogen at seeding treatment (1).

Crude protein per acre.—Highly significant increases in crude-protein production resulted from all spring nitrogen treatments, despite the general lowering in crude-protein content of grain and were in fact the direct consequence of higher grain yields.

The 60-lb. nitrogen treatment was outstanding, combining highest grain yield with a crude-protein content only slightly lower than the control, and actually giving double the protein yield of the latter. It was, moreover, noteworthy in giving a highly significant increase in crude protein in comparison with all the 30-lb. nitrogen treatments.

The figures obtained for the percentage recovery of nitrogen in the grain were higher than expected. The 60-lb. nitrogen application was highest with a 52 per cent. recovery, followed by 46, 43·6, and 40·2 per cent. for the three 30-lb. nitrogen treatments (2, 3, and 4) respectively, while for the application at sowing (1) the recovery figure was only 1·5 per cent.

Maturity.—Applying nitrogen at the 30-lb. rate in late March encouraged earlier ripening. The same dressing applied in late May delayed maturity by two days. Still later in ripening—by one day—were the no-nitrogen and the nitrogen-at-sowing treatments. It is likely that these differences in maturation date would have been greater in a less favourable growing season.

Straw yield.—The largest increases in straw resulted from the 30-lb. nitrogen dressing in late March (2) and the 60-lb. nitrogen dressing (5). The increases in straw weight were associated with significantly longer straw. In contrast, the nitrogen dressing in late May (3) gave significantly less straw and a significantly shorter mean straw length. The correlation between straw weight and ear-bearing plants was highly significant.

Discussion of Results

The results of this experiment clearly show the response of Cappelle wheat to nitrogen fertilizer in Aberdeenshire in 1955: and that the actual grain and straw responses were dependent on the quantity of nitrogen and the growth stage at which it was applied.

Contrary to other workers' findings [1, 2, 3] there was only an insignificant grain increase from an autumn dressing. It has been observed that high winter rainfall reduces the effectiveness of an autumn application of nitrogen [4, 5] and it may well be that an especially wet period which followed sowing—when a total of 6·57 in. of rain was recorded before the brairding of the wheat—was partly responsible for the lack of response in grain and straw in this experiment. Applying nitrogen in the form of Nitro-chalk may have been a predisposing factor, especially in respect of leaching-loss of nitrate [6]. The choice of nitrogen fertilizer was made with a view to encouraging plant establishment. It was presumed that the nitrate nitrogen would give the desired initial start to the wheat seedlings and that this would be later supplemented by the

oxidation of the ammonium nitrogen. But neither the plant stand at harvest nor the grain or straw yields gave support to this hypothesis.

In respect of spring application of nitrogen, the results of this investigation are generally in accordance with those of earlier trials [4, 5, 7]. For a given quantity of nitrogen fertilizer applied, comparing a late March dressing with a late May application, the early treatment gave a greater increase in yield and length of straw, without a significant difference in grain yield. There was further a significant increase in ear-bearing plants at harvest with the March application, but a lower nitrogen content of grain in comparison with the late May treatment.

On the basis of this trial, where wheat followed potatoes, the desirability of a divided dressing may be related to the level of nitrogen application. Grain and straw responses were strikingly in favour of the 60-lb. nitrogen application split into two dressings each of 30 lb. per acre. Indeed, grain and straw weight increases were sufficiently high with this level of nitrogen as to merit further work on this particular aspect.

Mention has been made of the lowered nitrogen content of the grain obtained with the spring nitrogen dressings. It is suggested that this depression was a direct consequence of the significant responses in yield of grain. Yields of crude protein per acre support this explanation. Nitrogen at 60 lb. per acre—given in two equal doses of 30 lb. in late March and late May—doubled the protein yield in comparison with the no-nitrogen treatment.

The rates of nitrogen recovery in the grain, for spring dressings, were considerably higher than those quoted for other trials [8, 9, 10] and are again indicative of the large grain responses obtained. It was unfortunate that facilities did not permit an evaluation of percentage recovery of nitrogen for total crop. The probability is that the recovery rate would have been even more emphasized in favour of early rather than late top-dressing where only one application of nitrogen was to be given in spring.

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FREQUENCY OF TWINNING IN A HERD OF EGYPTIAN COWS AND BUFFALOES

A. O. TANTAWY AND I. A. AHMED
(*Faculty of Agriculture, University of Alexandria, Egypt*)

Summary

Frequency of twinning in Egyptian cows and buffaloes, calculated from 419 and 313 parturitions respectively, and covering a period of fifteen years, was found to be 1·64 and 0·63 per cent. respectively. The twinning percentage increased with age of dams, reaching a maximum at about the ninth to the tenth year of age in both groups of animals.

Twin births tended to shorten the gestation period by about seven or twenty days in cows or buffaloes respectively. Gestation periods were about 282 and 299 days for twin births (sexes averaged) in the two species respectively.

Birth-weights for twins were less than those for singles, but weaning-weights of twins were higher than singles; there were no significant differences in subsequent weights, between twin and single births.

Twinning in cows and buffaloes increased the number of aborted calves compared with single births. Percentages of aborted twin calves were about 12 and 60 for cows and buffaloes respectively,while for singles there were about 5 per cent. for both species.

FREQUENCY of twinning in different breeds of European cattle has been investigated by many workers. Johansson [1] and Johansson and Venge [2] reported in Sweden a frequency of 1·90 and 0·44 per cent. for twinning in various breeds of dairy and beef cattle respectively. Lowe [3] found that, in German breeds of cattle, this frequency ranged between 0·25 and 4·50 per cent., while Engeler [4] reported that 2·70 per cent. of the total births in Brown Swiss cattle were twins. Joubert [5] gave a frequency of 1·3 per cent. in South African Friesian cattle, while Pfau *et al.* [6] found that the frequency in the same breed in the U.S.A. was about 3·95 per cent. Hewitt [7] showed that twin births in Red Poll and Friesian cattle were about 2·06 and 3·0 per cent. respectively.

Occurrence of twin births in buffaloes is rare; it has been found by Badreldin (personal communication) to be 0·75 per cent. in a commercial herd of buffaloes in Egypt.

The aim of the present study was to investigate the occurrence and frequency of twin births in Egyptian cows and buffaloes.

Material and Methods

Data used in the present study were taken from the records of a herd of Egyptian cows and buffaloes kept on the Alexandria University Farm, which covered a period of fifteen years (1942–56), comprising 419 parturitions in cows producing 217 males (a sex ratio of 107·4 males to 100 females), and 313 parturitions in buffaloes, giving 166 males (a sex ratio of 108·8 males to 100 females).

Management and treatment of this herd have been reported by Tantawy and Ahmed [8], who have also discussed the different characters concerning that herd for single births [8, 9, 10, 11].

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Results

Frequency of twinning. Of the parturitions by cows and buffaloes there were seven and two twin births respectively, which gives twinning frequencies of 1·64 and 0·63 per cent. Such a difference is due to differences between the species, which agrees with that reported by Hancock [12].

It has been reported by many workers that some females have an unusually high frequency of twinning among their calves. Hayden [13] reported a cow which gave five twin births out of seven. In the present study it has been noticed that one cow showed a high frequency: three pairs of twins out of six births.

From these results one may infer that the type of birth appears to be determined, beside the species differences, by the hereditary differences between females.

TABLE 1. *Frequency of Twinning in Relation to Age of Dams in Cows*

Sequence of calving	*No. of twin births*	*Age of dams (years)*
2nd	1	4
4th	1	6
6th–8th	5	9·2
9th and over	..	11·3

By tracing the pedigree of the seven pairs of twin births by cows, it was noticed that five pairs of these twins were half-sibs, and their sire was also a twin. This relationship could be taken as an indication that the sire may also be responsible for twinning. These results agree with those reported by Lush [14].

During the present study it was noticed that the percentage of abortions in cows which gave twin births was about 12·5 whilst it was 5·1 for single births. With buffaloes this percentage was about 60 for twin births and 5·1 for single ones. Aborted twin calves were dropped at about the seventh month of pregnancy in both groups of animals. Frequency of twin pregnancy, disregarding the aborted calves, was 1·90 and 1·59 per cent. for cows and buffaloes respectively. These results and the high percentage of abortions in buffaloes may explain the rarity of twin births in this species.

Twin births in relation to age of dams. The two pairs of twin births by buffaloes were dropped at the sixth calving, i.e. at an age between 9 to 10 years.

The relation between age of dams and the occurrence of twin births in cows is presented in Table 1.

Table 1 clearly demonstrates that the number of twin births in cows increased gradually with age of dams and reached its maximum at about the ninth year of age. Tantawy and Ahmed [8] have shown that age of dams is highly correlated with the number of former pregnancies. The variability of twinning is, therefore, correlated not only with age of dams but also with order of birth.

These results agree with those reported by Hewitt [7], Korkman [15], and Pfau *et al.* [6], who worked on European breeds of cattle.

Length of gestation period. Ahmed and Tantawy [10] showed that the average durations of gestation are 289·0±1·8 and 318·7±4·5 days for single births (sexes averaged) in cows and buffaloes respectively. Table 2 shows the average length of gestation periods for twin births in the two groups of animals.

TABLE 2. *Average Length of Gestation Period (days) for Twin Births in Cows and Buffaloes (sexes averaged)*

Item	*No. of twins*	*Average gestation period*
Cows . .	7	281·9±3·8
Buffaloes . .	2	298·5±2·0

Table 2 shows that twin births in both groups of animals tended to shorten the duration of gestation compared with single ones. Similar results have been reported by Hewitt [7], Pfau *et al.* [6], and Terrill and Hazel [16] for European breeds of cattle.

The differences between the length of the gestation period for the two types of birth, in the present study (about 7·1 and 20·2 days in cows and buffaloes respectively), are statistically highly significant.

Birth- and weaning-weights. Average of birth- and weaning-weights for single and twin births on cows and buffaloes are presented in Table 3, which shows that birth-weights for twins were less than those for single births for both species.

TABLE 3. *Birth- and Weaning-weights (kg.) for Single and Twin Births in Cows and Buffaloes (sexes averaged)*

Item	*Cows*		*Buffaloes*	
	Single births	*Twin births*	*Single births*	*Twin births*
Birth-weight [8] .	25·9 ±3·9	19·6 ±2·0	40·8 ± 4·3	25·1 ± 3·9
Weaning-weight [8]	79·7 ±9·7	82·0 ±6·8	108·0 ±13·3	123·3 ±19·1
Daily gain from birth to weaning [11]. . .	0·44±0·04	0·52±0·05	0·55± 0·03	0·82± 0·06

Table 3 also shows that the differences between single and twin birth-weights were about 6·2 and 15·6 kg. in cows and buffaloes respectively. Such significant differences may be attributed to the shorter gestation periods for twin births.

These results agree with those reported by Hewitt [7] who showed that birth-weight of twins was lower than that of singles.

Weaning-weights were higher for twin births than for single ones, but the differences are not statistically significant. It might be expected that the weaning-weight of single births would be heavier than that for twin births. These unexpected results could be attributed to the smaller number of twin births or to the fact that twins are usually better cared for than singles.

Daily gain from birth to weaning for single births was about 0·44 and 0·55 kg., while that for twins was about 0·52 and 0·82 kg., for cows and buffaloes respectively.

Weights subsequent to weaning showed no significant difference between the two types of birth, for cows, as shown in Table 4.

TABLE 4. *Weights in kg. for Single and Twin Births (sexes averaged) at Different Ages (months) for Cows*

Age in months	*Single births* [9]		*Twin births*	
	Weights	*Coefficients of variation*	*Weights*	*Coefficients of variation*
6 . .	98·0	23·0	100·3	19·2
8 . .	118·7	24·0	118·8	20·2
12 . .	175·6	21·0	183·3	22·5
18 . .	256·0	18·2	250·0	20·2

It appears from the results presented in Tables 3 and 4 that the lower birth-weights for twin births are not reflected in subsequent weights.

Conclusions

The observations made in the present study, although the data are not very extensive for twin births, indicate that frequency of twinning in Egyptian cows and buffaloes is very low. Twinning percentages were 1·64 and 0·63 respectively in the two groups of animals. The former percentage is very close to that found for the European breeds of cattle.

The high incidence of twinning for a particular cow, and the occurrence of twin births by cows which have been served by a twin sire, may indicate that twinning is determined by the genetic make-up of the parents, together with favourable environmental conditions, or by this twin bull being more fertile than the single bulls used in this herd. Joubert [5] concluded that high twinning percentage in cattle is probably due to the high standard of management, and selection for high fertility, while Holze [17] claimed that such twinning is due to the action of a sex-linked dominant gene.

The present work indicates that twinning in Egyptian cows and buffaloes occurs mostly in the sixth to the eighth parturitions and then decreases with the advance of the dam's age. These findings are in accordance with the general cycle of fecundity in most of the multiparous mammals.

Twins are carried by their dams for a shorter gestation period than single ones, which leads to a lower birth-weight. These results agree closely with those reported by Ward and Castle [18], Berger [19], and others. Weaning-weights for twin births in the two groups of animals are heavier than single ones, but there are no differences in subsequent weights, between single and twin births.

The results also show that twinning increases the percentage of aborted calves particularly in buffaloes; and further that females born as twins to males are hermaphrodite. It may be concluded, therefore, that twinning

is an undesirable character and efforts should be made to reduce its occurrence by following proper breeding and selection methods.

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COTTON INTERPLANTING EXPERIMENTS IN THE SOUTH-WEST SUDAN

K. R. M. ANTHONY[1] AND S. G. WILLIMOTT[2]

(*Yambio Experimental Farm, Research Division, Ministry of Agriculture, Sudan*)

Summary

Field experiments were carried out in the south-west Sudan (Equatoria) in the period 1952–5 to determine the feasibility of interplanting cotton into groundnuts, soya beans, cowpeas, or *Phaseolus angularis* planted at the beginning of the cropping season, so that cotton grew in association with the other crop for some weeks prior to harvest. If practicable, this system would have considerable merits under existing agricultural practice. The system of growing different food crops in admixture has been hallowed by long tradition in the peasant agriculture of tropical Africa.

Cotton thus interplanted with another crop suffered a reduction in stand and the plants suffered a growth setback with delayed budding. In the first season, with early-planted legumes and early cotton, good crops of both were obtained without serious loss of seed cotton.

Interplanting of cotton in later-sown crops resulted in a significant loss in cotton yield but was compensated by the yield of the other crop. The season, with good early and heavy late rains, was favourable to this type of rotation. But in the following two seasons the yields did not fulfil the promise of this earlier season. Nevertheless, the loss in cotton crop was offset in varying degrees by the additional yields of legume. This system, however, cannot be recommended for routine practice unless the legume crop is sown not later than early April, thus exerting minimum interference with the growth and yield capacity of the interplanted cotton.

In further studies of this problem it might be instructive to investigate the effect of locally available manures, such as compost and bat guano. This is a promising field of investigation where a cash crop and a food crop can be grown together without the risk of exhaustion or erosion of the soil.

APART from existing tree crops, cotton as a cash crop and the staple cereals and legumes as food crops represent almost the sum-total of agricultural production in the Zande district of Equatoria province of the south-west Sudan. Any experimental data on the feasibility of interplanting cotton with leguminous crops, such as groundnuts and the common pulses, would be of great advantage and obvious value in a country where the hunger for protein is almost pathological. Preliminary trials, carried out at the Yambio Experimental Farm in 1951–2, already indicated the practicability of planting cotton into different leguminous crops of short-growth periods, planted in early April, without seriously affecting the yield of cotton. The present paper records a series of field experiments carried out with the object of determining the feasibility of this system under local conditions of peasant agriculture. The results and conclusions reached in experiments up to 1955 are discussed and evaluated.

The introduction of cotton as a cash crop and the establishment of a

[1] Senior Agronomist. [2] Senior Chemist.

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local cotton industry in the Zande district (Zandeland) formed the backbone of what has come to be known as the 'Zande Scheme'. Prior to the commencement of cotton growing for the Zande Scheme in 1945, chillies supplied the only exportable cash crop of the south-west Sudan. From past experience in Zandeland, at Maridi and in the neighbouring districts of the Belgian Congo, it had been shown that American Upland cotton (*Gossypium hirsutum* L.) could be successfully cultivated under local conditions of shifting agriculture. The ultimate target of the Zande Scheme aimed at approximately 117,000 small kantars[1] of seed cotton per annum. The average production over the last decade has shown considerable variation with an average annual production of the order of 50,000 small kantars of seed cotton. The area under cultivation reached its maximum of about 23,000 feddans[2] in the 1951–3 seasons although the annual yield per feddan was variable and the actual production often fell severely short of expectation.

The original variety chosen was BAR SP/84 which, from the Maridi trials, was known to give consistently good yields of seed cotton with a high G.O.T.[3] Moreover, the quality was satisfactory. The variety SP/84, originally selected at Serere, Uganda, from a Barberton strain, was made homozygous for the B2 factor for blackarm resistance (BAR) by Knight. More recently, as a result of systematic trials at the Yambio Experimental Farm, a variety BAR 11/5 gave a better over-all performance and consequently was being bulked for replacement. A further development was the replacement of BAR 11/5 by the variety BAR 7/8·1, which proved to have a still higher G.O.T. and hence a considerably enhanced yield of cotton lint.

Because of its remoteness and primitive character Zandeland is never likely to become an importer of its staple food requirements. Nor is it desirable that it should, and it is incumbent on the cultivator to increase the production of local food crops whilst growing the cash crop. This basic necessity has been accepted and forms an essential feature of the present pattern of crop husbandry in this area. Staple food crops include eleusine, maize, groundnuts, sesame, and cassava apart from the perennial fruit crops. Sorghums, cowpeas, grams, and rice are also grown but in small proportion to the staple crops.

The system of growing food crops in association, in the peasant agriculture of tropical Africa, has been hallowed by long traditional practice and is the fruit of hard experience. Mixed cropping is adopted as a common practice by the native as an insurance against total failure of the crops as a result of attacks by pests and diseases and extreme variations in the weather. A mixture, not only of crops but even of varieties, is intentionally sown, with the result that the variety or crop best suited to the local conditions flourishes at the expense of the others. For example, groundnuts are usually interplanted with maize; eleusine with sorghum, kenaf (*Hibiscus cannabinus* Linn.) for string production, and cassava. Eleusine and sesame or hyptis are other common associates.

[1] Small kantar = 100 rotls = 100 lb. (approx.).
[2] Feddan = 1·038 acres.
[3] G.O.T. = ginning out-turn, i.e. the percentage of lint to seed cotton.

Apart from a little cucurbit (*Citrullus colocynthis* L.), interspersed among the crop with the ubiquitous cassava, no intercropping of cotton is practised by the Azande.[1]

The Zande district of south-west Sudan lies along the Nile–Congo Divide and comprises an area of 17,534 square miles with a population of Azande of approximately 168,000, giving an average population density of 9·6 per square mile [1]. While Yei and Zande districts carry the highest average population densities of the province, it is noteworthy that certain areas are almost devoid of population. Under a recent resettlement scheme native cultivators were allocated holdings of about 32 feddans for cultivation and for regeneration of soil fertility in the long-term bush fallow. Each chiefship is divided up into units known as *gbarias*, which can best be described perhaps as dispersed villages. Each gbaria includes about fifty families and covers an area of up to 3 square miles. A family unit has an average of only 2½ feddans actually under crop. The *gbarias* are laid out along straight lines, kept open as cycle tracks, and beside which each cultivator is required to build his house so as to allow of easy access and supervision by the Inspectors of Agriculture. A detailed account of the Zande Scheme up to 1954 is given by Ferguson [2].

The Zande district lies wholly in the tsetse fly belt; consequently the peasantry do not practise animal husbandry and have no tradition of it. The diet is of necessity vegetarian, animal protein being available in small amount only during the dry season when hunting is possible. The Research Station is situated about 3 miles east of the village of Yambio, the district headquarters. The annual rainfall at the station (altitude 2,300 feet) averaged 1,450 mm. for the period 1949–54. There were 130 days of measurable precipitation per annum. The soils are latosols with pea iron gravel (murram) dominating the profile. They are acid in reaction, generally free-draining and leached, and although of low inherent nutrient status certain of the loams of the Yambio area have considerable cropping capacity. The soils are formed mostly *in situ*, the underlying rocks being mainly gneisses and granites, frequently overlain by laterite. A short discussion of the soils of Zandeland is given in a recent paper by Anthony and Willimott [3].

There is a dry season extending over three months from December to February. March rains, however, are unreliable and planting usually commences in April. It is possible to take off the soil two short-growing-period crops in succession, a common succession being groundnuts followed by eleusine. Local varieties of groundnuts have planting-to-harvest periods of 85–95 days and for eleusine 110–20 days. Farther south it it usual to plant cotton after groundnuts. A system of taking a crop of a quick-growing legume in advance of the main cotton crop would have certain advantages, provided always that the yield of cotton was not unduly affected. There would be economy of labour in that one opening of the bush fallow would suffice for two crops and that the cultivations on the first crop (legume) could be expected to reduce the weeding required in the early stages of the second (cotton). This system

[1] Azande, plural form of Zande.

would also be of benefit to the soil in reducing the liability to sheet erosion sometimes encountered in cotton plots. At the same time this would allow of an increase in acreage under a protein-rich crop. It might also have the effect locally of putting cotton growing in a more favourable light with the peasantry. Early June is the optimum period for cotton sowing. Crop yields from later plantings fall off rapidly with the date of planting. Early plantings result in boll opening during the rains. It is not possible to plant cotton after the harvest of an earlier crop without excessively retarding the planting date.

There remains the possibility of growing a leguminous crop entirely separate from the cash crop by planting it so early (e.g. the beginning of March) that it can be harvested before sowing cotton. Here again rainfall, in determining the available soil moisture, is the limiting factor but there are indications that the system might be practicable with the grams and with cowpeas. No crop, subsistence or cash, receives any manuring in Zande agricultural practice. In any future experiments it might be instructive to study the effect of manuring, especially with nitrogen, on the intercropping system. The use of chemical fertilizers is of course excluded by local conditions but compost is available and also some rich if limited deposits of bat guano. The application of such available manures would be a logical development.

Experiments in 1952–3

Two field trials were initially laid down. In the first, the legumes were planted at the earliest possible date; in the second at an average late date. In one experiment there were five interplanting treatments (cotton alone, and cotton interplanted into groundnuts, soya beans, cowpeas, and *Phaseolus angularis* respectively). There were two planting dates of cotton (2 June, 30 June) giving in all ten combinations, in five randomized blocks. Plot size was 50 sq. m. harvested. Land was opened from bush fallow in the second half of March and crops were planted on 3 April at a spacing of 30×30 cm. Normal close spacing was necessarily retained in view of the intensity of weed growth. The interplanted cotton, variety BAR 11/5, was spaced 90×30 cm. and thinned to two plants per planting point. Cowpeas, Phaseolus, and soya beans were harvested in the third week of June and groundnuts on 1 July. At harvest the stalks were laid between the cotton rows.

In the second experiment treatments and layouts were similar except that the land was opened in the second half of April and the earlier crops planted on 2 May. As a result cowpeas and Phaseolus were not harvested until mid-July, and soya beans and groundnuts not until the end of July.

Two dry periods occurred in June and early July, which led to conditions unfavourable for the establishment of cotton in association with the earlier planted crops. Establishment of the cotton was also affected by interplanting, particularly where the two crops were longest in association. Percentages of blank planting points are given in Table 1.

At the time of harvesting the early crops the interplanted cotton without exception looked far from promising. Apart from the influence of

the associated crops on stand, growth was depressed and the growth rate was retarded for approximately one month after the harvest of the

TABLE 1. *Percentage of Blank Planting Points of Cotton*

Cotton planted	*Early-planted legumes*		*Late-planted legumes*	
	2 June	*30 June*	*2 June*	*30 June*
Cotton alone	11	21	11	28
+groundnuts	21	19	23	28
+soya beans	16	29	20	49
+cowpeas	9	20	30	42
+Phaseolus	19	31	28	49

earlier crops. Recovery was then rapid. The later-planted cotton was less depressed. Height data of the cotton plants are summarized in Table 2.

TABLE 2. *Average Height of Cotton Plants (cm.)*

Cotton planted	*Early-planted legumes*						*Late-planted legumes*					
	2 June			*30 June*			*2 June*			*30 June*		
Days after sowing cotton	*20*	*50*	*145*	*20*	*50*	*145*	*20*	*50*	*145*	*20*	*50*	*145*
Cotton alone	12	33	91	10	30	89	..	33	83	9	29	91
+groundnuts	9	13	77	7	18	75	11	18	74	10	16	76
+soya beans	10	19	86	9	28	87	..	15	75	8	17	80
+cowpeas	10	18	81	9	25	82	10	12	77	9	16	81
+Phaseolus	9	18	87	8	19	76	9	15	74	8	15	75

Associated with retarded growth was a prolongation of the growing period with delay in budding. This was reflected in the period from planting to mean picking date (Table 3) and was most pronounced where the period during which the crops were growing together was the longest.

TABLE 3. *Planting to Mean Picking Date (days)*

Cotton planted	*Early-planted legumes*		*Late-planted legumes*	
	2 June	*30 June*	*2 June*	*30 June*
Cotton alone	165	158	165	161
+groundnuts	183	165	192	171
+soya beans	174	161	192	169
+cowpeas	174	161	197	170
+Phaseolus	174	163	185	179

Yield data are tabulated in Table 4. For the earlier-planted legumes, only groundnuts produced a significant decrease in cotton yield. An excellent crop of *Phaseolus angularis* and average crops of soya beans and cowpeas were obtained without a significant loss of cotton. The later cotton plantings showed a decline in yield in conformity with previous experimental work in the area. Later plantings of the legumes resulted in a significant reduction in cotton yield. But in one instance only did

the yield of seed cotton fall below 50 per cent. of the control. Moreover, a satisfactory average yield of the associated crop was realized with each treatment. Even with the sowing of legumes at a later date the production of the crops grown together was greater than the total expected production from the two individual crops sown separately in plots of half the acreage. For successful field practice, however, the planting of legumes cannot be delayed.

TABLE 4. *Crop Yields (rotls per feddan)**

	Early-planted legumes					*Later-planted legumes*				
	Seed cotton			*Legumes*		*Seed cotton*			*Legumes*	
Cotton planted	*2 June*	*30 June*	*Mean*	*2 June*	*30 June*	*2 June*	*30 June*	*Mean*	*2 June*	*30 June*
Cotton alone .	1,342	1,003	1,172	..	..	1,476	1,037	1,256	..	..
+groundnuts	841	827	834	1,687	1,714	875	672	773	1,372	1,284
+soya beans .	1,221	866	1,043	490	538	769	703	736	755	609
+cowpeas .	1,236	1,051	1,143	608	692	729	746	737	703	623
+Phaseolus .	1,360	932	1,146	824	939	980	718	849	977	1,045
Mean . .	1,200	936	1,068	..	..	966	775	870	..	..
	Sowing date (P = 0·01)		*Interplanting* (P = 0·05)			*Sowing date* (P = 0·01)		*Interplanting* (P = 0·05)		(P = 0·01)
Significant difference	132		155			111		127		172

* 1 rotl per feddan (r.p.f.) = 0·99 lb. per 1·038 acre = 1 lb. per acre (approx.).

Experiments in 1953–4

In the following season, 1953–4, a field trial was devised to compare cotton planted alone with cotton planted into *Phaseolus angularis*, the most promising of the associated crops. In connexion with another investigation three cultural treatments were superimposed. The layout consisted of the six combinations of the two crop treatments and three cultural treatments, replicated five times.

The land was opened at the end of March but lack of rain delayed planting of Phaseolus until 20 April, too late for minimum interference with cotton growth. Cotton was interplanted on 2 June and beans harvested on 6 and 21 July. The cotton stand was not seriously affected by this planting into beans; 9 per cent. blank holes occurred as compared with 3 per cent. in cotton alone.

In conformity with the previous year's results, cotton growth was depressed by the associated crop and although growth rate increased after harvest, and hoeing-in of the Phaseolus stalks, the final height of the cotton crop averaged only 85 cm. as compared with 110 cm. when it was grown alone. In addition the period of vegetative growth was lengthened by nearly 10 days. The mean budding period for interplanted cotton was 73 days and the mean maturation period 164 days after planting, as compared with 62 days and 154 days respectively for cotton grown alone.

Cotton planted under normal practice averaged 1,359 r.p.f. seed cotton compared with 838 r.p.f. when planted into beans. In the latter case, however, a crop of 870 r.p.f. beans was also obtained.

In order to assess the possibility of putting this type of association into practice a further trial was kindly undertaken on our behalf by the

Equatoria Projects Board on cultivators' holdings near the Station. All the work of cultivation was undertaken by the peasantry. Plots included cotton alone, cotton planted into soya beans, and cotton planted into Phaseolus.

Most of the legume crops were planted by the middle of May, too late for best results. Cotton was planted in mid-June, and that which was interplanted suffered the usual setback and produced a later crop than the cotton grown alone. Satisfactory yields of cotton and the associated crop were, however, obtained and the trial demonstrated that this type of interplanting could be carried on satisfactorily at the farmer's present level of cultivation. Yield data are summarized in Table 5.

TABLE 5. *Crop Yields of Peasant Cultivators*

	Cotton + Soya beans	*Cotton alone*	*Cotton + Phaseolus*	*Cotton alone*	*Cotton alone, all plots*
No. of cultivators	8		9		17
Total area (feddans)	4·89	5·29	5·41	4·91	10·20
Seed cotton r.p.f.	624	438	471	473	455
Beans r.p.f.	477	..	508	..	..

Experiments in 1954–5

In the 1954–5 season a third randomized-block experiment, with six replications, was devised to compare cotton alone with cotton interplanted into groundnuts, soya beans, cowpeas, and *Phaseolus angularis*. The leguminous crops were planted in early April and cotton was interplanted on 1 June. As in the previous two years, cotton interplanted suffered a reduced stand and growth set-back, accompanied by delayed flower-bud formation. Yield data are summarized in Table 6.

TABLE 6. *Crop Yields* (*rotls per feddan*)

	Legume	*Seed cotton*
Cotton alone	..	1,169
+groundnuts	546	629
+soya beans	890	528
+cowpeas	534	816
+Phaseolus	550	897
Significant difference (P = 0·01)		161

Although the loss of cotton yield was offset by satisfactory yields of the earlier-sown crops in the 1952–3 season, the later results did not realize this earlier promise. It is believed that an important factor in the success of the crop association in that season can be ascribed to the unusual late heavy rains in November, which favoured the late-maturing cotton plants interplanted into legumes. For normal conditions in the south-west Sudan, with the emphasis on cotton production, this system cannot be recommended unless it is possible to secure early planting of the first crop. Provided always that the legume is planted in early April the system obviously has merits.

Discussion

Some suggestive experiments on intercropping were carried out by R. T. Paterson at Kadugli, Nuba Mountains, and referred to by F. Crowther [4]. Cotton was sown at a row spacing of 90 cm. with 75 cm. between holes, and rows of groundnuts alternated with rows of cotton.

As usual the highest yields of cotton resulted with no intersowing of groundnuts (Treatment 1), but a reasonably good yield of groundnuts was obtained from the same land at the same time, at the cost of only a moderate reduction in cotton yield (Treatment 2). The relative yields of the two crops could be adjusted by changing the sowing-dates; the yields of both crops were highest with the earliest sowings but relatively

TABLE 7. *Intercropping Experiments* (*Average of 2 years*[4])

Treatment	*Yields r.p.f.*	
	Cotton	*Groundnuts*
1. Cotton alone	749	..
2. Cotton and groundnuts sown same date as (1) . .	534	591
3. Groundnuts sown same date as (1), cotton 14 days later	461	688
4. Cotton and groundnuts both sown 14 days later than (1)	650	167
5. Cotton sown 14 days later and groundnuts 28 days later than (1)	655	93

more groundnuts could be obtained by sowing them first and delaying the cotton slightly. If both were sown late the cotton did not suffer greatly but the groundnut crop was a failure (see Table 7). Other legumes have been tried amongst cotton but usually their climbing habit renders them less suitable than groundnuts for intercropping. Although the treatments applied in the Kadugli experiments are somewhat different from those at Yambio, the conclusions to be drawn are in general agreement with the later experimental work here recorded using a wider range of legume associates. As F. Crowther rightly observes, here is a promising line of research, well suited to peasant cultivation, where a cash crop and a food crop can be grown simultaneously and the land neither exhausted nor exposed to soil erosion.

Acknowledgements. It is a pleasure to acknowledge our indebtedness to Professor Sir Frank Engledow for much valuable criticism.

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A NOTE ON THE NUTRITIVE VALUE OF *ACACIA CYANOPHYLLA* SEEDS

D. RAMADAN
(*Department of Agriculture, Cyprus*)

ACACIA CYANOPHYLLA, commonly called 'Acacia' in Cyprus, has been grown in the island for many years. It has been used to stabilize sand dunes for some fifty years and it is grown on poor, rocky land to provide shelter for livestock, fuel, and small agricultural timber. It has long been observed too that sheep and goats grazing in acacia plantations obtain a considerable amount of fodder from the fresh foliage within their reach, and from the dry leaves and seeds which have fallen to the ground. In consequence, plantations of this species are now made with the definite purpose of providing forage for livestock, but no attempt has been made, until the present study, to estimate the value of any part of the plant as animal fodder. In 1953 a sample of seed was sent by the Conservator of Forests, Cyprus, to the Imperial Institute, London, for chemical analysis. The results of this analysis are given below.

Composition of Acacia Cyanophylla *Seed*

	Per cent.
Moisture	7·3
Crude protein	30·7
Ether extract	12·9
Nitrogen-free extractives (by difference)	30·9
Crude fibre	13·0
Ash	5·0

Subsequent analyses carried out in the laboratory of the Department of Agriculture, Cyprus, showed a rather lower crude-protein content, which, however, was still higher than that of undecorticated-cotton-seed cake. The seed was found by the Imperial Institute to contain no cyanogenetic glucocides and was therefore potentially of value as a feeding-stuff for livestock. From the economic point of view, too, there were definite possibilities, since the Forest Department records yields of as much as 150 lb. per acre of plantation and, very important, the seed is available in the autumn and early winter, when forage is in short supply.

Feeding trials with chicks as described below, were carried out at the Department of Agriculture to investigate the possibilities of the use of acacia seed as a source of protein concentrate.

The Gross Protein Value of Acacia Seed

In one trial the Gross-Protein-Value technique was used to estimate the feeding value of the protein in acacia seed, using day-old Rhode Island Red chicks. There were three treatments and three replicates of each treatment, each replicate containing nine chicks. Up to 14 days of

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age, the chicks were all fed on a ration complete in all other known nutritional requirements, but deficient in protein. The chicks were then separated into the various groups and the following mixtures were fed over a period of 21 days:

(*a*) a mixture of maize and wheat as a 'cereal control ration';
(*b*) a casein and cereal mixture to give the 'casein control';
(*c*) an acacia seed and cereal mixture to give the 'acacia mixture'.

Food intake was approximately the same with all three mixtures. The chicks were weighed before and after the experiment and the mean weight gained per chick was calculated. The results are shown in Table 1.

TABLE 1. *Gross Protein Value of* Acacia cyanophylla *seeds*

Fodder	*Percentage crude protein*	*Mean weight gained after 2 weeks, gm.*	*Protein Utilization**	*Gross protein value†*
Cereal control . .	10·1	52·5	..	..
Casein control . .	13·0	101·7	16·4	100
Acacia mixture . .	13·0	77·5	8·3	50·6

* Gain in weight over cereal control, per gm. of supplementary protein.
† Least significant difference (P = 0·05) = 13·2.

The Optimum Level of Acacia Seed in the Diet

The three cereal control groups from the above experiment were used in the second experiment. One was fed on a constant mixture of cereal control ration and acacia seed. For the other two groups the proportion

TABLE 2. *Gain in Weight of Chicks Fed on Rations Containing Varying Amounts of Acacia Seed*

	Group		
	I	*II*	*III*
1st week			
Acacia seed (per cent.)	11	17	22
Rate of growth (gm. per chick per week) . .	14·4	15·6	20·3
2nd week			
Acacia seed (per cent.)	11	34	44
Rate of growth (gm. per chick per week) . .	19·2	21·7	14·4
3rd week			
Acacia seed (per cent.)	11	68	88
Rate of growth (gm. per chick per week) . .	21·6	14·4	4·2

of acacia seed to the cereal control ration was gradually raised. The chicks were weighed weekly. The proportion of acacia seed in the ration and the weekly gains per chick are recorded in Table 2.

Discussion

The results of the first experiment indicate that the Gross Protein Value of *Acacia cyanophylla* seed is about the same as that of groundnut meal, with a value of 50 [1, 2].

The results of the second trial cannot be treated statistically, but they suggest that a cereal-acacia seed mixture containing about 22 per cent. of the latter gives the best results with chicks and that rations containing up to 34 per cent. of acacia seed have no ill effects. Higher percentages of acacia seed appear to retard the rate of growth. This may be partly due to the high percentage of ether extract and crude fibre in acacia seed but also to the reduction of food intake when the proportion of acacia seed in the diet is raised above 34 per cent.

Further investigations using other types of livestock are in progress. If they prove successful, a new and valuable source of protein will have been found in Cyprus, where the shortage of such food is a severe limiting factor to livestock development.

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THE ECOLOGY AND CONTROL OF WEEDS AT TOZI IN EAST CENTRAL SUDAN

A. H. BUNTING AND J. D. LEA
(*Research Division, Sudan Ministry of Agriculture*)

Summary

When *Acacia seyal-Balanites aegyptiaca* woodland with tall grass is cleared for mechanized farming, on the semi-arid clay plains of the central Sudan, the annual grasses which are the main herbs of the natural vegetation soon disappear under cultivation. The most serious weed in the first two years is *Ipomoea cordofana*, but this bindweed can be controlled by efficient cultivation as well as by spraying with 2,4-D, either before sowing of late-planted crops or after emergence in sorghum. In the third and fourth years several dicotyledonous weeds tend to become important. The perennial *Lactuca taraxacifolia* suckers freely and seeds abundantly; *Corchorus tridens* is an annual whose abundant seed will go on germinating all through the season. Other potentially serious weeds are *Desmodium dichotomum*, *Celosia argentea*, *Kohautia grandiflora*, and *Phyllanthus maderaspatensis*. *L. taraxacifolia* and *P. maderaspatensis* are strongly, and the others slightly, resistant to 1 rotl/feddan (roughly equal to 1 lb./acre) of 2,4-D. A potent source of infestation is the seed of weeds growing-on after harvest, particularly in crops such as sesame which do not use all the available water in the soil. Careful rotational farming practice and efficient and timely cultivations, including late disking where necessary, has given generally good control of all these weeds so far, though emergency measures including hand-weeding have had to be applied locally to deal with infestations of *L. taraxacifolia* and *C. tridens*. Thus even in the second or third year free competition of weeds for 25–60 days had no effect on crop yields in a series of experiments.

The witchweed *Striga hermonthica* is present in localized areas in the natural grassland: these foci of infestation persist after clearing. Hand-weeding and burning and the use of herbicides in a rotational farming system appear to offer an effective control of the parasite, provided they are applied from the start.

Regeneration of woody elements of the original vegetation is common but is only potentially serious in the case of a Zizyphus species which has been controlled on a small scale with 2,4,5-T esters.

Apart from the control of *I. cordofana* and of Striga herbicides do not seem to have an important place in general agriculture at Tozi at this stage. Sesame appears more sensitive to 2,4-D applied shortly before sowing than either cotton or groundnuts. In the field, drift damage to American cotton by 2,4-D has been negligible.

In 1952 a research station was opened at Tozi (N. lat. 12° 30′, E. long. 34° 00′) in the eastern clay plains of the Central Sudan, to study methods of rain-fed arable farming for this hitherto undeveloped area with an annual rainfall of 25 to 30 in. The main crops grown (by mechanized means so far as possible) are cotton, groundnuts, sesame, sorghum, and maize. This paper records the experience of weed incidence and control gained in the four initial years.

The climate is semi-arid. An average of about 28 in. of rain falls annually, in a single rainy season from mid-June to early October, and the remaining months of the year are virtually rainless. Although the months of December and January are usually cool, at least at night, the

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screen maxima rise later, values up to 44° C. being recorded in February to May. Throughout the dry season the dewpoint is below 10° and often below 0° C., though more humid southerly air may move in for a few days at a time in March and April, anticipating the seasonal change in May and June. The intense heat and desiccation of the latter part of the long dry season is an important feature of the environment and potently opposes the survival of plants. During the rainy months the daily maxima and minima lie around 30 and 20° C. respectively, with dewpoints around 20° C., the temperatures being stabilized by the great heat capacity of the moisture-retentive alluvial soils. These are deep, level, alkaline, cracking clays, with pH from 8·5 to 9·0 and a montmorillonitic-clay content around 70 per cent. There is no permanent water table, at least within the first 35 ft. The soil-moisture régime thus exhibits a wetting or humid phase, when rainfall penetrates, through cracks at first and then in bulk, at a rate and to an ultimate extent depending on the balance between percolation and evapo-transpiration; and a drying phase, after the rains, when water is removed according to the specific capacity of the vegetation or crop to withdraw moisture against increasing tension and to penetrate to the limit reached by the water. In natural vegetation, and under sorghum, cotton, safflower, and groundnuts, the moisture removal is more or less complete and the soil becomes heavily cracked; sesame and maize do not remove all the water. Through the dry season the top foot of the soil loses more water by evaporation, partly into the cracks.

The original vegetation of the 1,250 feddans[1] cleared for cultivation at Tozi was an *Acacia seyal-Balanites aegyptiaca* woodland with tall grass containing areas of treeless open grassland (*sagiyat*). The herbaceous flora consisted mainly of upright annual grasses, reaching 6 to 10 ft. in height, with dicotyledonous herbs, many of them twining amongst the grasses. The formation is widespread on the clay plains of the Sudan south of the 25-in. rainfall isohyet.

The Weed Flora and Its Ecology

The herbaceous plants in the natural vegetation tend to occur in pure and often localized sub-communities, suggesting strongly that the formation is not in equilibrium and is probably largely secondary. In the first clearings at Tozi in 1952 (mainly from open grassland), the frequency of individual weed species, other than the ubiquitous *Ipomoea cordofana*, varied considerably from field to field. Since then, certain of these weeds have become less common while others have begun to spread generally throughout the arable area. It may still be several years before the weed flora is stable and uniformly distributed.

The main constituents of the ground flora in the wild vegetation are annual grasses. Of these, the more important species are *Sorghum purpureo-sericeum*, *Rottboellia exaltata*, *Hyparrhenia* spp., *Sorghum* sp., *Beckeropsis nubica*, *Ophiurus papillosus*, and *Cymbopogon nervatus*. Although these appear in profusion when the land is first cultivated, they have succumbed to mechanized cultivation and weeding more

[1] 1 feddan = 1·038 acres.

readily than the majority of dicotyledonous herbs. Provided the fields are well cleaned in the first year, the grasses present no special problems in subsequent years. In fact on third- or fourth-year land annual grasses may be altogether absent. The same applies to two perennial grasses, *Setaria incrassata* and *Ischaemum brachyatherum*, which are not very common in the natural vegetation at Tozi, although difficulty has been

TABLE 1. *Principal Dicotyledonous Weeds found at Central Rainlands Research Station, Tozi, and their susceptibility to 1 rotl per feddan of 2,4-D Sodium Salt*

Group I. Consistently killed by 1 r.p.f. 2,4-D sodium salt.
Group II. More generally killed, but sometimes only severely checked.
Group III. Not killed, but growth may be temporarily checked.

Species	*Growth habit and season*	*Response to 1 rotl / feddan 2,4-D sodium salt*
Acalypha crenata	Erect annual	II
Borreria phyteuma	Erect annual	III
Celosia argentea	Erect annual	II
Chrozophora plicata	Prostrate perennial	II
Clitoria ternatea	Prostrate perennial	III
Commelina forskalii	Prostrate annual	II
Corchorus olitorius	Erect annual	I
Corchorus tridens	Bushy annual	II
Crotalaria sp. *aff. C. astragalina*	Erect annual	III
Desmodium dichotomum	Erect annual	II
Emilia sp. *aff. E. coccineae*	Erect perennial	III
Euphorbia aegyptiaca	Prostrate annual	II
Hibiscus esculentus	Erect annual	I
Hybanthus enneaspermus	Erect annual	III
Ipomoea cordofana	Prostrate perennial	I
Kohautia grandiflora	Erect annual	II
Lactuca taraxacifolia	Erect perennial	III
Momordica tuberosa	Prostrate perennial	III
Phyllanthus maderaspatensis	Erect annual	III
Phyllanthus niruri	Erect annual	II
Rhynchosia minima var. *prostrata*	Prostrate perennial	III
Thunbergia annua	Erect annual	II
Vigna pubigera	Prostrate annual	II
Vigna vexillata	Prostrate perennial	III

reported in controlling the latter in non-rotational mechanized farming in the Gedaref district (with similar climate and soils) where it is apparently more widespread.

Dicotyledonous herbs, unlike the grasses, persist under cultivation, and some of them have tended to increase, although the majority are also well controlled by normal mechanized-farming practice (see below). The most common species on land cropped for three to four years at Tozi are listed, together with their response to 1 rotl[1] per feddan of 2,4-D sodium salt applied in water solution, in Table 1. Three species, *Ipomoea cordofana*, *Lactuca taraxacifolia*, and *Corchorus tridens*, present special problems.

[1] 1 rotl = 1 lb. (approx.).

Ipomoea cordofana. This is a diffuse perennial bindweed with long trailing stems. It is by far the most troublesome weed on virgin land at Tozi. It readily regenerates after disking, and the long prostrate stems may impede or even prevent mechanical inter-row cultivation. There is extensive vegetative regeneration from shallow lateral as well as deeper roots. Suckers do not appear to arise at depths greater than 1 ft., so that regeneration is probably complete once moisture has penetrated well beyond this depth.

Lactuca taraxacifolia. This is an erect, rapidly growing, yellow-flowered perennial composite herb, growing at Tozi in small, localized, roughly circular communities which spread from year to year, each presumably the progeny of a single plant. It is a vigorous, freely seeding, aggressive invader and has accordingly been strictly controlled. Second-year plants have a strong tap root which descends more or less vertically, while there are some lateral roots. The tap roots, but not the laterals, may give rise to 1 to 3 vegetative shoots at depths down to 1 ft.; these appear at the surface from August onwards. It is not known whether the plants can regenerate in this way in the first year. Sucker regeneration after weeding is very strong. In an area of a little more than 1/500 feddan, 429 Lactuca shoots (205,000/feddan), which had not yet produced seed, were removed on 26 July 1955. On 10 September a further 636 shoots (301,000/feddan), none of which had yet set seed, were removed, and on 1 December (well into the dry season) another 606 (288,000/feddan) were removed. After this weeding there was no further regeneration. A shoot may set seed 6 weeks after its emergence from the soil.

Corchorus tridens. This is a bushy, erect annual herb up to 2 ft. high, and was by far the most serious weed at Tozi in 1955, which seemed to be a particularly favourable year for it. It produces large quantities of small, light seeds which germinate continuously throughout the rainy season. Thus in late September or early October, when the rains are almost over, dense patches of seedlings may still be present in fields which have already been weeded several times. These plants can grow on after the crop is harvested and so provide a copious source of weed seed for the following season. In general *Corchorus tridens* is comparatively rare in the natural vegetation, but it spreads rapidly in arable land if not controlled.

Striga hermonthica. This parasite of sorghum is common in the fields of cultivators in many parts of the rainlands, and is found in *Sorghum purpureo-sericeum* grassland at Tozi. In the grassland, where it flowers at the same time as its host plant in mid-September, *S. hermonthica* occurs mainly in dense (up to 210 individuals per sq. yd.) and localized (about 10 to 30 sq. yds.) communities which cause a general reduction in the vigour of grass growth. Such localized communities persist in cultivated sorghum at Tozi on land recently brought in to cultivation from grassland, and the resulting infestations have been removed each year by hand and burnt. It appears that rotational farming, together with vigorous eradication of the parasite from the start, can prevent it from spreading from the initial foci of infestation; and *S. hermonthica* has generally not

been at all serious at Tozi so far. It has now been shown [1, 2] that *S. hermonthica* can be controlled with 2,4-D sodium salt. With this assistance there is no apparent reason why it should present any difficulties in the development of farming on the clay plains.

Another species of Striga, *S. gesnerioides*, is often found on *Ipomoea cordofana*, but has not so far been recorded on any crop plant.

Woody regeneration. *Acacia seyal*, *Acacia campylacantha*, and *Balanites aegyptiaca*, the principal trees of the natural vegetation at Tozi, do not regenerate vegetatively to any large extent on newly cultivated fields, provided the land is well stumped when first cleared. On the other hand, regeneration of *Zizyphus* sp., which grows in small widely scattered thickets in the Acacia woodland, is more serious. Lateral roots remaining in the soil after clearing produce dense coppices of growth, up to 5 ft. high, which remain in leaf for most of the dry season. As this species occurs only rarely at Tozi, it has in no way hindered development, but where it is more common serious difficulty might be experienced in eliminating it. It can be killed by spraying a 5 per cent. solution of 2,4,5-T esters in diesel oil (equivalent to 20 lb. 2,4,5-T in 100 gallons) but the residual effects of such treatment are not known.

Three perennial woody herbs or shrubs, *Cephalocroton cordofanus*, *Combretum aculeatum*, and *Clerodendrum* sp. near *hildebrandtii*, are not readily eliminated by the standard cultural operations at Tozi, but as they are very rare in the area, no detailed work has been done on their ecology and control. Sodium tri-chloracetate at 50 lb./feddan, and isopropyl phenyl carbamate at 20 lb. plus 2,4-D sodium salt at 5 lb./feddan did not control *C. cordofanus* in the Gedaref area [3]. At Tozi this species has tended to decline under rotational farming.

Agricultural Practices in Relation to Weeds

Cultivations. The mechanical means of controlling weeds in field-scale plantings at Tozi have been described in detail elsewhere [4]. The heavy soil cracks deeply and is self-mulching on drying. The main operations before sowing consist of from one to three shallow diskings to kill weeds and level the seed-bed. Much depends on the timing of these operations, which are of course quite useless if conducted before general germination of weed seeds has taken place. After sowing, in row crops, a steerage hoe, or front-mounted flat sweeps, are used for inter-row cultivations, and the flat sweeps are also used for ridging in groundnuts. These operations, supplemented by normal hand weeding (particularly if wet weather impedes mechanical work) satisfactorily control most of the weeds listed in Table 1.

Infestation after harvest. The development of weed infestations from plants remaining after harvest can become very serious, and is most likely to occur in sesame stubble. In 1954 and 1955 this crop came to maturity before soil moisture was exhausted. This can apparently happen also in maize and occasionally in other crops also, particularly in years of high total rainfall or when the late rains are heavy. In a sesame crop the early weeds are suppressed or checked by the growing crop once it is well established (though it is unable to compete effectively with

weeds in the seed bed), but after harvest the persisting weeds grow vigorously and, being free from competition, set a heavy crop of seed in November and December. Weeds most likely to multiply rapidly in this way are *Corchorus tridens*, *Desmodium tortuosum*, *Celosia argentea*, *Kohautia grandiflora*, and *Phyllanthus maderaspatensis*.

This possibility of late build-up of weed seed reinforces the importance of effective weed control in the growing crop. Where this has not been adequate, disking after harvest, or in appropriate cases spraying with 2,4-D sodium salt, will be essential.

Crop sequences and rotations. The results of a weed count in a crop sequence experiment at Tozi in the years 1952–3 are given in Table 2.

TABLE 2. *Numbers of Weeds in Sorghum (000/feddan) in 1953, after Clean Weeding in Various Crops, and Natural (tumbledown) Fallow, in the Previous Year*

Treatments, 1952	*Annual herbs*	Ipomoea cordofana	Vigna *spp.*	*Grasses*	Clitoria ternatea	*Total*
Tumbledown fallow	18·2	3·8	1·4	0·8	0·4	24·6
Clean weeding in:						
Sesame . .	5·7	0·2	0·2	0·2	trace	6·3
Lubia . .	5·7	0·1	0·1	0·2	0·0	6·1
Bare fallow. .	5·6	0·1	0·1	0·1	0·0	5·9
Groundnuts .	5·3	0·2	0·1	0·2	trace	5·8
Sorghum . .	4·8	0·1	0·1	0·1	0·0	5·1
Safflower . .	4·0	0·1	0·1	0·2	0·0	4·3

The 1952 treatments in this experiment, which was laid out on newly-cleared land which had been disked twice, were various crops (groundnuts, sorghum, sesame, safflower, lubia—*Dolichos lablab*) and a bare fallow, all clean weeded by hand when necessary; and a natural or tumbledown fallow. In the following year the whole experiment was planted to sorghum after two pre-sowing diskings. The weeds were counted at the time of the first hand-weeding in 1953.

Clean weeding in 1952 reduced weed populations in 1953 to about one-quarter of those present after tumbledown fallow. The control of *Clitoria ternatea* was virtually complete. After tumbledown fallow the figure for grasses, 800 plants per feddan, is low compared with annual dicotyledonous herbs (18,200 per feddan) because the grasses were largely controlled by the two initial diskings in 1952. These results show the effectiveness of normal means of weed control in a population consisting so largely of annual plants.

Although on four years' experience the longer-term effect of the various sequences and rotations in use at Tozi cannot be assessed with any precision, useful experience has accumulated on the effect of individual crops on a field scale. The close planting of sorghum now adopted in field practice at Tozi (in 1955 around 100,000 plants/feddan in 12-in. rows, although populations around 50,000 are now preferred in 24-in. rows) suppresses the weeds entirely, provided planting is complete, with no missed areas. This crop also provides an opportunity for

the use of 2,4-D sodium salt (see below). Late-planted safflower, which dries out the soil completely to a depth of 120 cm., is generally more or less weed-free at harvest as well, largely because the land is kept clean through the rains in preparation for the crop. Sesame, in which the small size of the seedlings prohibits early mechanical weeding, may contain quite large numbers of weeds while groundnuts and cotton appear to form an intermediate group. At Tozi in 1955 there were more weeds in

TABLE 3. *Effect of Time of First Weeding on Yield of Groundnuts, 1954*

Date of first weeding	*Days from planting*	*Plant no. 000/feddan*	*Kernels r.p.f.*
		(±1·0)	(±76)
15 July	8	44·6	1,460
20 July	13	41·7	1,422
26 July	19	43·4	1,391
1 August	25	46·2	1,414
12 August	36	42·4	1,112
26 August	50	42·1	942
Least significant differences:			
P = 0·05		3·0	224
P = 0·01		4·1	306

groundnuts, following cotton or sesame and receiving fertilizer nitrogen,[1] than in cotton, which followed an efficient bare fallow. In groundnuts inter-row cultivation and ridging largely control the weeds (except for the continuously germinating *Corchorus tridens*), and persistent weeds in the row are killed when the crop is dug, so that the total effect, under good management, can be to reduce weed populations considerably.

In special cases it may be necessary to use a bastard or semi-fallow year if a particular field becomes too severely infested; this could easily happen, particularly with *C. tridens*, under careless management. A bare fallow is not now regarded as suitable for this purpose, as it has been found to exert unfavourable effects on subsequent crops. Considerable improvements in yield have, however, been seen in the field as a result of the growth of moderate but controlled weed populations on fallows; the analysis of this effect, and attempts to imitate it agriculturally using sorghum or other cheaply-drilled crops, now represent an important line of inquiry at Tozi.

Effect of weeds on crop yields. The influence of varying periods of free weed competition in the earlier stages of growth on the yield of cotton and groundnuts was measured experimentally in the 1954 and 1955 seasons (Tables 3–6). Plots were left unweeded for various periods, up to 65 days from planting, and then kept clean to maturity. In 1955 the weeds removed from each plot in the first weeding were weighed green in the field.

[1] Short-season (90–95 days) groundnuts at Tozi respond more markedly to nitrogen fertilizers, including ammonium nitrate and urea, than any other crop with the possible exception of maize. This is thought to be due to inefficient nitrogen absorption by this leguminous crop in the 40 days or so before there is any release of nitrogen from the abundant, large, and apparently effective nodules.

TABLE 4. *Effect of Time of First Weeding on Yield of Barberton Groundnuts, 1955*

Date of first weeding	*Days from planting*	*Plant no. 000/feddan*	*Green wt. of weeds r.p.f.*	*Kernels r.p.f.*
		(±0·9)		(±37·8)
28 August	39	28·0	694	1,586
2 September	44	28·2	655	1,502
7 September	49	26·8	1,545	1,562
13 September	55	27·8	2,875	1,546
19 September	61	27·6	3,809	1,364
24 September	66	26·8	4,680	1,398
2 October	74	27·0	5,233	1,329
12 October	84	25·2	5,101	1,234
Least significant differences:				
P = 0·05		2·6	..	108
P = 0·01		3·4	..	144

TABLE 5. *Effect of Time of First Weeding on Yield of BAR 7/8·1 Cotton, 1954*

Date of first weeding	*Days from planting*	*Plant no. mean 000/feddan*	*Mean*	*Seed cotton r.p.f.*	
				S. half	*N. half*
		(±2·0)	(±51)		(±80)
19 July	11	39·2	1,211	1,219	1,202
24 July	16	40·5	1,245	1,215	1,280
1 August	23	41·8	1,262	1,343	1,180
7 August	29	41·7	1,251	1,329	1,175
16 August	38	36·8	1,180	1,298	1,062
4 September	57	36·9	1,123	1,222	1,020
Least significant differences:					
P = 0·05 . . .		5·8	150	..	254
P = 0·01 . . .		8·0	205	..	360

TABLE 6. *Effect of Time of First Weeding on Yield of BAR 7/8·1 Cotton, 1955*

Date of first weeding	*Days from planting*	*Plant no. 000/feddan*	*Green wt. of weeds r.p.f.*	*Seed cotton r.p.f.*
		(±2·0)		(±33·9)
18 July	19	55·8	278	1,264
23 July	24	59·1	394	1,274
28 July	29	57·8	608	1,288
3 August	35	56·9	1,857	1,292
7 August	39	52·0	2,454	1,237
12 August	44	57·3	3,615	1,136
23 August	55	55·9	11,390	1,157
2 September	65	58·7	14,352	994
Least significant differences:				
P = 0·05		6·0	..	96
P = 0·01		8·0	..	129

In 1954 (Table 3) weed competition affected groundnut yields only if the first weeding was delayed beyond 25 days. Such delays in weeding, until 36 and 50 days, reduced the yield from about 1,400 to 1,100 and 940 r.p.f. of kernels respectively. In the 1955 experiment (Table 4) weed growth was light. At the first weeding, 39 days after sowing, the green weight of weeds was barely 700 r.p.f., the corresponding yield being nearly 1,600 r.p.f. kernels. There was no apparent effect of weed competition until first weeding was delayed to 61 days, when 3,800 r.p.f. green weight of weeds was present and the yield was reduced to 1,360 r.p.f. of kernels.

In cotton in 1954 the critical time of first weeding was much the same as in groundnuts (Table 5). With up to 29 days' free competition the yield was 1,175–1,280 r.p.f. seed cotton, but further delay in weeding reduced yields to 1,020–60 r.p.f. In 1955 (Table 6) there was no effect of competition during the first 39 days, but if weeding was delayed to 44 days, when 3,600 r.p.f. fresh weight of weeds was present, about 100 r.p.f. was lost. The quantity of weed growth necessary to produce loss was thus similar in groundnuts and cotton.

The Use of Herbicides

Some elementary information on the use of herbicides, principally 2,4-D sodium salt, has been gained and appears worth brief record. The susceptibility of the more important dicotyledonous weeds to 1 r.p.f. of 2,4-D sodium salt is shown in Table 1. *Ipomoea cordofana* is particularly susceptible; as little as 0·25 r.p.f. gave a good kill on small plots in 1953. The control of this weed is facilitated by sowing as much new land as possible to sorghum, of a relatively late-sown dwarf variety. In this way an extended period of mechanical weeding can be followed if necessary by the use of 2,4-D sodium salt in the crop.

In 1954 *Lactuca taraxacifolia* appeared resistant to 2,4-D sodium salt at normal rates (1–2 r.p.f.). In 1955, spray applications of sodium chlorate (with a fire retardant) at 100 and 800 r.p.f., of 80 per cent. 2,4-D sodium salt at 10 and 20 r.p.f., and of 2,4,5,-T esters at roughly 2 and 20 rotls equivalent acid/feddan, were compared (Table 7). The treatments were applied either before or after the emergence of suckers on newly weeded plots. No wetting agent was used in this experiment.

Although at 41 days after the original weeding a high degree of control appeared to have resulted from most treatments, complete control at 3 months was obtained only with the higher rate of 2,4,5-T esters, and only about one-quarter of the original stand remained where 2 r.p.f. of the esters or 800 r.p.f. of the chlorate preparation had been given. 2,4-D sodium salt had reduced the population to three-quarters, at either rate. 100 r.p.f. chlorate had given no reduction. On untreated plots the populations were 50 per cent. above the original level at 41 days, when all plants on them were again removed, and 40 per cent. above at 90 days. The vigour of the plants was much reduced by the treatments, but practically all which survived produced seed, even if only in small quantities.

Later observations, using a wetter, showed practically complete

control by 8 r.p.f. 2,4-D sodium salt. The relatively high tolerance of *L. taraxacifolia* to herbicides is in accordance with general experience with perennial species.

Corchorus tridens can be controlled in sorghum, where the effect of crop competition is added to that of the herbicide, by 1 r.p.f. of 2,4-D; but its control in this way would be troublesome because of the long period over which new seedlings are produced.

TABLE 7. *Effect of Pre- and Post-emergence Applications of Three Herbicides at Two Rates on* Lactuca taraxacifolia, *1955*

Material	*Rate r.p.f.*	*Time of application*	*Population, per plot (1/500 feddan)*		
			*Before treatment**	*41 days*	*90 days**
			Number and (in parentheses) percentage increase or decrease		
None	..	..	215	318 (+48)*	303 (+41)
Sodium chlorate preparation	100	Pre-emergence	133	127 (−4)	125 (−6)
		Post-emergence	162	183 (+13)	148 (−9)
		Mean	148	155 (+5)	136 (−8)
Sodium chlorate preparation	500	Pre-emergence	196	8 (−96)	46 (−76)
		Post-emergence	223	13 (−94)	56 (−75)
		Mean	210	10 (−95)	51 (−76)
2,4-D sodium salt	10	Pre-emergence	190	6 (−97)	147 (−23)
		Post-emergence	224	71 (−68)	142 (−37)
		Mean	207	38 (−82)	144 (−31)
2,4-D sodium salt	20	Pre-emergence	146	0 (−100)	107 (−27)
		Post-emergence	164	17 (−90)	115 (−30)
		Mean	155	9 (−95)	111 (−28)
2,4,5-T esters	2	Pre-emergence	204	7 (−97)	49 (−77)
		Post-emergence	226	6 (−97)	80 (−64)
		Mean	215	6 (−97)	64 (−70)
2,4,5-T esters	20	Pre-emergence	184	0 (−100)	3 (−98)
		Post-emergence	203	0 (−100)	21 (−90)
		Mean	194	0 (−100)	12 (−94)

* Pulled out as counted.

In simple trials in 1954 the effects of pre-emergence applications of 2,4-D sodium salt at 0·5 and 1·0 r.p.f. on cotton, sesame, groundnuts, and sorghum were investigated. The first three crops were sown within 2 days of spraying, and their rate of emergence was reduced. In cotton and groundnuts the stand at harvest was not affected by the treatment, so that the effect was probably a check to growth only, but in sesame the

stand was heavily reduced. In sorghum, sown a fortnight after spraying, the stand was quite unaffected by the treatments.

In the sorghum and sesame experiments weed growth was light and apparently unaffected by the treatments. In cotton and groundnuts the growth of weeds, though markedly reduced by the herbicide, in the earlier stages at any rate, was still sufficient to require hand-weeding.

The yields of groundnuts (1,070 r.p.f. kernels) and sorghum (1,200–60 r.p.f.) were not reduced by 2,4-D sodium salt at the lower rate. At 1·0 r.p.f. there were reductions of about 100 r.p.f. in each case, though the differences were not statistically significant. Yields were reduced by both rates of herbicide in cotton and sesame.

Though pre-emergence application of 2,4-D sodium salt does not appear to offer any advantages at Tozi at this stage, because of the wide range of susceptibility of the weed species, field-scale control of *Ipomoea cordofana* was carried out by post-emergence spraying in sorghum in 1955. In the Gezira [5] and elsewhere [6, 7] damage to young sorghum by 2,4-D preparations has been reported, but rates up to 1 r.p.f. applied 3 to 4 weeks after sowing did no harm to this crop at Tozi in 1954 and 1955. Pre-sowing applications of 2,4-D sodium salt can be used to control *I. cordofana* before relatively late-sown crops such as groundnuts and dwarf sorghum.

With such applications there is some risk of drift damage to young cotton in neighbouring fields, though not to other crops, so far as our experience goes. Even in cotton the damage is slight. Usually, with normal care, only a few plants along the margins of a field will be affected. In Egyptian cotton in the Gezira a far greater sensitivity is reported. (The more volatile ester formulations of 2,4-D have not been used at Tozi.) The symptoms of 2,4-D damage seen at Tozi are identical with those described and illustrated by Lawes [8] at Kano in Nigeria.

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THE VALUE OF SEAWEEDS IN ANIMAL FEEDINGSTUFFS AS A SOURCE OF MINERALS, TRACE ELEMENTS, AND VITAMINS

W. A. P. BLACK AND F. N. WOODWARD
Institute of Seaweed Research, Inveresk, Midlothian

Summary

In general, seaweeds are a good source of the vitamins A, C, D, E, and K, and fed at the 10 per cent. level should provide the requirements of most livestock, but will contribute only small amounts of the other vitamins. As a mineral supplement, seaweeds are capable of providing only sodium chloride and iodine in sufficient amounts to meet the animal's requirements and are of little value as sources of calcium or phosphorus, except perhaps in the case of dairy cows where sufficient calcium might be derived from 10 per cent. of Ascophyllum meal. They are, however, valuable sources of the trace elements copper, cobalt, manganese, and iron and other elements which have, perhaps, not yet been recognized as essential for the animal.

Seaweed meal is superior to dried grass for the provision of all trace elements and most vitamins.

Although the calculations have been based on the addition of 10 per cent. of seaweed to the ration, this is not to be regarded as the optimum amount for each animal. Unfortunately, there is still insufficient experimental evidence to give these optimum quantities.

It must be borne in mind, however, that all the calculations are theoretical only as there is still no practical evidence of the availability to the animal of the minerals, trace elements, or vitamins present in seaweed.

SEAWEED meal is now being produced commercially as an animal-feed additive in Canada, Denmark, France, Great Britain, Holland, Ireland, Norway, South Africa, and the United States while Germany is importing appreciable quantities. The combined output in these countries exceeds 50,000 tons per annum and is rapidly increasing. In Great Britain, although the industry did not start until 1950, about 7,000 tons per annum are now being produced and the demand exceeds the supply.

Despite the number of feeding and digestibility trials which have been carried out in many countries [1], giving results which have not always been in accord, the value of seaweeds in livestock rations is still open to some question. Such trials as have been undertaken, have in many cases been of limited value owing to their short duration and the non-realization that marine plants differ markedly in composition from terrestrial plants and undergo even greater seasonal variation. The results of these trials have indicated, however, that the brown seaweeds can only be regarded as an additive or supplementary foodstuff. This is due in large measure to the fact that they are unbalanced in respect to proteins and carbohydrates and are unusually high in mineral matter. The trials have shown, however, that, with pigs, seaweed can be introduced up to 10 per cent. of the basal ration without affecting the growth rate or the quality of the bacon. With high-yielding dairy cows, 10 per cent. of their concentrate ration can be replaced by seaweed without any noticeable effect

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on the milk yield or butter-fat content, although on many farms 8 oz. seaweed meal per day during the winter months resulted in a marked increase in milk yield and butter fat. With day-old chicks, up to 5 per cent. of seaweed meal can supply all their vitamin A and D requirements and with laying hens 10 per cent. of the basal ration can be replaced by seaweed without any detrimental effect. The addition of 3 per cent. of seaweed to the basal ration of the laying hen was found to supply the β-carotene necessary to give the standard yoke colour. When fed to dairy cows and laying hens marked increases in the iodine content of the eggs and milk were observed. Although in many of the trials conducted to assess the value of seaweed in feeding stuffs no beneficial effects resulted, it must be borne in mind that in these cases seaweed replaced an equal amount of a carefully balanced diet which could not be improved by further addition.

The value of seaweeds as a source of energy, particularly in the case of the sublittoral brown seaweeds, will depend greatly on the time of harvesting. Only in the spring of the year is the protein content reasonably high (12–15 per cent. of the dry matter), and this falls rapidly as growth proceeds, so that for the greater part of the year it is 5–10 per cent., consequently seaweeds cannot be regarded as a source of protein. Their value in the animal's ration might, therefore, be attributed principally to the minerals, trace elements, vitamins, and growth-promoting factors which they have been shown to contain. For this use they can be harvested at any time of the year, which is not possible with any land crop where the time of harvesting is usually well defined and of short duration.

The following assessment is based on published chemical analytical data for dried seaweed as well as on analyses undertaken for this investigation using samples prepared under controlled conditions, and it has been assumed that the amounts determined by chemical analysis are available to the animal.

Seaweed meal is frequently compared with dried grass as a feed additive, despite the fact that grass is now chiefly used as a source of protein for the ruminant and as a vitamin supplement for the non-ruminant. For comparative purposes, therefore, such relevant analytical data as are available for grass are included in the tables.

It is virtually impossible to make generalizations about 'dried grass', however, owing to the paucity of accurate analytical data and the variability of the product. It may be made from herbage of different types growing on different soils and harvested at different stages of growth. In addition, grass drying is generally undertaken in small units of varying types by non-technical personnel so that drying conditions vary considerably from place to place. For this reason a range of values is given where possible: where single figures are quoted they must be taken as indicative only of the order of magnitude of the constituent in question.

Seaweed meal by contrast is a much more uniform product. In Britain only one species, *Ascophyllum nodosum*, is used at present, and if the industry expands still further only two more species (*Laminaria cloustoni* and *Rhodymenia palmata*) are likely to be brought into use. The

chemical composition of these marine algae has been much more thoroughly worked out than that of even the commonest grasses. Furthermore, the total output of the seaweed-meal industry is produced in a relatively small number of large dryers which are operated under controlled factory conditions.

Experimental

Analysis of seaweed meals. Five seaweeds, representative of the brown, red, and green marine algae, were gathered, dried at 60–80° C. as soon as possible after collection and milled to pass a 64-mesh screen prior to analysis. A proximate analysis was carried out by the standard methods used for animal feedingstuffs [2] and the results are given in Table 1.

TABLE 1. *Analyses of Typical Dried Seaweeds* (*dry-weight basis*)

Seaweed	*Total ash* %	*Crude protein* %	*Crude fat* %	*Crude fibre* %	N-*free extractives* %
Cladophora rupestris (Chlorophyceae) Dunbar, Jan. 1955	29·3	30·5	0·48	16·6	23·1
Rhodymenia palmata (Rhodophyceae) North Berwick, Jan. 1955	27·4	23·4	0·26	2·1	46·8
Laminaria meal (*L. cloustoni* frond) (Phaeophyceae) Campbeltown, Nov. 1954	21·8	12·6	0·38	5·0	60·2
L. cloustoni stipes (bulked sample) Jan./Dec., Oban, 1946	37·6	8·4	0·25	9·6	44·1
Ascophyllum meal (*Ascophyllum nodosum*) (Phaeophyceae) Loch Maddy, Dec. 1954	24·5	7·6	2·62	8·4	57·8
Grasses [9]	9–10	11–27	2·3–3·8	22–44	38–53

Sodium, potassium, calcium, magnesium, phosphorus, silica, chlorine, and sulphate were determined by the methods given in Piper's *Soil and Plant Analysis* [3] and iodine by the method of Baggesguard-Rasmusses and Bjerrescø [4]. The results are given in Table 2.

The trace elements recorded in Table 3 were determined by Dr. R. L. Mitchell, Macaulay Institute for Soil Research, employing the method already reported [5], while the vitamins were determined by Dr. R. W. Carroll, Quaker Oats Company, Chicago, U.S.A., using the methods given in *Methods of Vitamin Assay*, 2nd edition, 1951 (Interscience Publishers Inc., New York). The vitamin results are given in Table 4 together with average figures obtained by a number of analysts and extracted from the literature.

Vitamin C was determined in the fresh algae [22]. It is not known if it is destroyed on drying.

Discussion

Considerable doubt still exists as to the minimum mineral and vitamin requirements of different types of livestock and appreciable variations can, of course, occur depending on the type and breed, and on age, stage of development, rate of production, &c. Dairy cows, pigs, and poultry have been selected for the purposes of the present study and the contribution of 10 per cent. of seaweed meal in their basal diet calculated on the basis of published data [6, 7, 8]. It is assumed that the seaweed meal is the sole source of each of the constituents, although in all cases the constituents of the basal diet will also contribute to the animal's requirements.

TABLE 2. *Mineral Composition of Typical Dried Seaweeds*, % (*calculated on dry basis*) *compared with Pasture Herbage*

Seaweed meal	Na	K	Ca	Mg	I	P	SiO_2	Cl′	SO_4''
Cladophora rupestris . .	2·50	3·28	1·52	0·73	0·11	0·27	7·1	6·34	4·62
Rhodymenia palmata . .	2·07	7·91	0·72	0·39	0·03	0·56	2·2	9·70	1·06
Laminaria meal *L. cloustoni* frond	2·88	5·25	1·04	0·58	0·50	0·28	0·6	5·92	3·06
Laminaria meal *L. cloustoni* stipe	1·35	8·15	1·80	0·73	0·33	0·25	0·5	12·48	2·54
Ascophyllum meal *Ascophyllum nodosum* . .	2·90	2·26	2·16	0·82	0·05	0·09	5·0	1·89	6·95
Grasses [10] .	0·13	1·99	0·37	0·24	0·00005 [11]	0·21	..	0·50	..

With dairy cows consuming 10¼ lb. concentrates per day, of which 10 per cent. is seaweed meal (Table 5), *Cladophora rupestris* and *Ascophyllum nodosum* might provide all the animal's calcium requirements for maintenance, while *Rhodymenia palmata* and Laminaria frond could only provide half the amount. The phosphorus in *Rhodymenia palmata*, Laminaria frond, *Cladophora rupestris*, and *Ascophyllum nodosum*, on the other hand, could only provide 26, 13, 12·5, and 4 per cent. of the cow's phosphorus requirements, showing that seaweed meals cannot be regarded as a satisfactory source of phosphorus. In addition, the seaweed meals might provide all the animal's sodium chloride and iodine requirements; 10 per cent. of seaweed meal in the concentrate ration is capable of providing ten times the amount of iodine required. In regard to vitamin A, the Ascophyllum meal contains sufficient provitamin A (carotene) to provide 77 per cent. and the Laminaria meal 39 per cent. of the cow's requirements, but if fucoxanthin is also a precursor of vitamin A, as appears to be likely, the seaweeds will satisfy the animal's maintenance requirements.

TABLE 3. *Trace-Element Content of Seaweeds Compared with Pasture Herbage in p.p.m. dry matter*

	Co	Ni	Mo	Fe	Pb	Sn	Zn	V	Ti	Cr	Ag	Cu	Mn	Ba	Sr
Cladophora rupestris . .	16·2	20·0	2·44	4,400	38	<5	92	24	550	6·4	< 0·7	31	1,260	40	112
Rhodymenia palmata . .	2·60	16·4	0·83	1,355	28	<5	200	29	100	34	1·0	48	110	21	90
Laminaria meal . . . *L. cloustoni* frond	0·37	1·28	0·25	437	7·9	<5	170	1·0	18	1·4	0·2	4·6	< 20	28	650
Laminaria meal . . . *L. cloustoni* stipe	0·48	2·88	0·29	446	5·4	<5	59	2·5	26	1·3	0·9	5	47	43	2,500
Ascophyllum meal . . *Ascophyllum nodosum*	1·43	3·35	1·25	1,132	<4	<5	110	5·9	114	2·9	< 0·3	61	45	27	560
Mixed Pasture Herbage [12]	0·14	3·1	0·82	56	1·6	0·4	56	0·06	1·4	0·1	..	4·6	..	108	37

TABLE 4. *Vitamin Contents (p.p.m.) of Seaweed and Grass Meals*

	Ascophyllum meal	*Laminaria meal (frond)*	*Dried grass*	Cladophora rupestris	Rhodymenia palmata
β-carotene	16–25 [13] 35, 68. 56, 126 [15]	11–14 [13] 85 45 [15]	100–450 [14]	..	..
Fucoxanthin (possible precursor of vitamin A)	90, 238 [15]	469 [15]	..	..	..
Thiamine (B_1)	1·4–5·4* [16]	1·3–7·2† [16]	2·0–3·3 [17]	1·9	1·5
Riboflavin (B_2)	7·5	2·4	8·6–12·0 [17]	5·9	5·3
Pantothenic acid	0·2* [18]	0·28† [18]	8·6–15·5 [17]	..	..
Niacin	12·3	19·4	29·7–40·7 [17]	26·2	28·9
B_{12}	0·004 [19]; 0·08 [20]	0·06–0·12 [19]	Nil [14]	..	..
C	2,674 [22]	2,094 [22]	Destroyed [14]	..	..
D_3	0·01 [20]	n.d.	0·01–0·03 [21]	..	..
E	156, 298 [23]	29·9, 25·4 [23]	111 [24]	..	..
K [25]	14·2	n.d.	16·7	..	..
Folic acid [26]	0·07	0·31	n.d.	..	..
Folinic acid [26]	0·07	0·60	n.d.	..	..

* *Fucus vesiculosus.* † *Laminaria saccharina.* n.d. not determined.

Table 6 gives the requirements of the laying hen and shows that 10 per cent. of seaweed in their diet might provide all the sodium chloride, iodine, and vitamin A and E requirements besides contributing to their

TABLE 5. *Dairy Cows. Contribution of Seaweed Fed as 10 per cent. of the Concentrate Ration* [27] *where the Cows Consumed 10¼ lb./day of Concentrates*

Constituent	Cladophora rupestris	Rhodymenia palmata	*Laminaria meal (frond)*	*Ascophyllum meal Loch Maddy Dec. 1954*	*Maintenance requirements of a cow (c. 1,000 lb.) per day*
	g.	g.	g.	g.	g.
Ca	7·06	3·34	4·84	10·05	10
P	1·25	2·60	1·30	0·42	10
NaCl	29·6	24·6	34·1	34·3	28
Mg	3·39	1.81	2·70	3·81	10
I	0·51	0·14	2·32	0·23	0·20
A	..	..	15,500 i.u.	31,000 i.u.	40,000 i.u.
D	..	..	..	460 i.u	3,000 i.u.

TABLE 6. *Poultry. Contribution of Seaweed Fed as 10 per cent. of the Basal Ration of Laying Hens Consuming 150 g. of ration/day*

	Laminaria meal (frond)	*Ascophyllum meal*	*Minimum requirements of laying hen*
Ca	0·16 g.	0·32 g.	3·0 g.
NaCl	1·01 g.	1·11 g.	0·4 g.
Vitamin A	500 i.u.	1000 i.u.	650–800 i.u.
D_3	n.d.	15 i.u.	90–110 i.u.
E	0·45 mg.	4·5 mg.	0·5 mg.
K	n.d.	0·21 mg.	0·17 mg.
B_1	0·08 mg.	0·05 mg.	0·3 mg.
B_2	0·04 mg.	0·11 mg.	0·43 mg.
Nicotinic acid	0·29 mg.	0·19 mg.	2·7 mg.
Pantothenic acid	0·004 mg.	<0·004 mg.	1·7 mg.
Folic acid	0·005 mg.	0·001 mg.	0·11 mg.
Vitamin B_{12}	0·001 mg.	0·001 mg.	0·007 mg.

TABLE 7. *Pigs. Vitamins Provided per lb. of Feed by Seaweed Fed as 10 per cent. of the Ration*

Vitamin	*Ascophyllum meal*	*Laminaria meal*	*Porkers 5–12 weeks*	*Requirements of pigs 3–6 months*	*Sows*
A	3,000 i.u.	1,500 i.u.	500 i.u.	600 i.u.	2,200 i.u.
D_3	46 i.u.	..	50 i.u.	50 i.u.	50 i.u.
B_1	0·15 mg.	0·19 mg.	0·5–0·8 mg.	0·5–0·8 mg.	0·5 mg.
B_2	0·34 mg.	0·11 mg.	0·8 mg.	0·8 mg.	0·8 mg.
Nicotinic Acid	0·58 mg.	0·88 mg.	2·2–5·0 mg.	2·2–5·0 mg.	2·2–5·0 mg.
Pantothenic Acid	<0·01 mg.	0·013 mg.	3·4–4·5 mg.	4·5 mg.	..
B_{12}	0·003 mg.	0·004 mg.	0·009 mg.	0·009 mg.	0·009 mg.

vitamins B_1, B_2, and B_{12}, folic, nicotinic, and pantothenic acid requirements. As a source of calcium the seaweed meals are, however, inadequate.

With pigs, the figures given in Table 7 show that the seaweed meals

might be expected to provide their vitamin A and D requirements and contribute to their vitamins B_1, B_2, and B_{12}, nicotinic and pantothenic acid requirements.

Little is known of the trace-element requirements of livestock. It appears, however, that for sheep seaweed might provide the necessary copper and cobalt so often deficient in certain hill areas, and the iron so essential to the pig.

From the chemical data available, Ascophyllum meal appears to be superior to dried grass as a source of calcium, iodine, and sodium chloride and all trace elements but not of phosphorus. On a weight-for-weight basis the two types of meal appear to be approximately comparable in the provision of vitamins A, B_1, B_2, K, and perhaps D_3: seaweed meal is superior in its vitamin B_{12}, C, and E contents and inferior in niacin. Insufficient is yet known to permit any conclusions being drawn as to their relative values for the provision of vitamin B_6, biotin, folic, and folinic acids.

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THE RESISTANCE OF GROUNDNUTS TO CERCOSPORA LEAFSPOTS

J. S. HEMINGWAY
(*Tanganyika Agricultural Corporation*)

Summary

The literature on the resistance of groundnuts to leafspots caused by two *Cercospora* spp. is reviewed; references indicate that degrees of resistance exist in a number of varieties. The association of resistance with some characters of habit, length of season, and foliage colour has been studied in Tanganyika; detailed comparisons of disease incidence and development have been made on resistant and susceptible varieties. It is suggested that infection is dependent on a critical stomatal size, and that the slower rate of expansion of lesions on resistant varieties is due to their more substantial leaf tissues.

CERCOSPORA PERSONATA (Berk. and Curt.), Ell. and Everh., and *C. arachidicola* Hori are universally found on groundnuts (*Arachis hypogaea* L.). The effects of severe epidemics on yield, and the difficulty of harvesting defoliated and moribund plants have been described by the present authors [1]. *C. personata* develops into destructive epidemics more commonly than does *C. arachidicola* [2].

A wide range of control measures has been investigated, but most authors recommending controls (e.g. rotations, fungicide treatments) stress the necessity for the development of resistant varieties [3, 4, 5, 6]. These authors mention differences in varietal susceptibility which are known to exist. Sauer [7] considered it necessary to investigate the resistance of wild *Arachis* spp.; in this respect Chevalier [8] reported that six species indigenous to Brazil were susceptible to *C. personata*. Several authors have specified particular varieties as resistant to the disease [9, 10, 11, 12, 13]. The 'Spanish' type is invariably recorded as susceptible or very susceptible [10, 14, 15, 16, 17, 18], whereas decumbent and runner varieties show some degree of resistance [10, 12, 15, 18, 19, 20]. Conclusions of resistance have been drawn from general field observations, fungicide trials, and various scoring systems but no evidence of the precise nature of the resistance character has been brought forward.

Higgins [21, 22] described a programme of crossing resistant plants with others (particularly 'Spanish') of high yield and good-quality oil, but he has written (personal communication) that no worthwhile lines were produced which combined these desirable characters. He suggested [21] that resistance to the two species appeared to be inherited independently.

The Identification of Resistance

The collection of groundnut varieties established at Kongwa in 1950–1 totalled 135, and included types from all parts of the world. All varieties were planted in observation plots for recording of characters of habit, length of season, yield, oil content, foliage colour, and resistance or susceptibility

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to Cercospora. A preliminary classification for habit and length of season was devised by Lea (1952, unpublished):

Bunch habit: the central axis and lateral branches are erect.

Semi-bunch habit: the central axis is erect; the lateral branches spread out from the base of the plant and then curve upwards.

Runner habit: the central axis is erect; the lateral branches are completely prostrate.

There are transitional types between these groups, classified as 'spreading bunch' and 'spreading semi-bunch'. For the length of season, varieties were classified as 'early' (100–10 days to maturity), 'medium' (110–20 days), and 'late' (120–30 days). The foliage colour was recorded as either light or dark green.

Using this classification, the numbers of varieties in each category were:

	Light-green foliage	*Dark-green foliage*
Early		
Bunch	97	0
Spreading bunch	0	0
Semi-bunch	0	0
Spreading semi-bunch	0	0
Runner	0	0
Medium		
Bunch	0	1
Spreading bunch	0	2
Semi-bunch	0	10
Spreading semi-bunch	0	1
Runner	0	0
Late		
Bunch	0	0
Spreading bunch	0	2
Semi-bunch	0	9
Spreading semi-bunch	0	7
Runner	0	6

There appear to be correlations between length of season and colour of foliage and between length of season and growth habit. (Dital and Mehta [23] prepared a classification of varieties in India and recorded the constant association of dark foliage with late maturity and with smaller, more numerous leaflets than on varieties with light-green foliage.)

When the Kongwa collection was planted in 1951, visual estimates of the degree of incidence of Cercospora were made on several occasions during growth, and towards maturity the extent of defoliation was estimated. Without exception varieties with light-green foliage (including numerous 'Spanish' types) were susceptible or very susceptible, while all with darker foliage showed some degree of resistance to the disease. These comparisons were repeated in subsequent seasons, the early-bunch 'Natal Common' being used as a standard of susceptibility. Several

other varieties were included in the trials, such as 'San Jose No. 3' found resistant in the Philippines [18], 'Mbambey 24–11' from Senegal [12], and 'Mwitunde' a Tanganyika variety resistant to Rosette diease [24].

Characteristics of Habit and Length of Season of Varieties Showing Resistance to Cercospora Leafspots

Resistance	*Variety*	*Origin*	*Season*	*Habit*
Very resistant	'H.G. 1'	India	Medium	Bunch
	'Matevere'	Tanganyika	Late	Semi-bunch
	'Kanyoma'	Tanganyika	Medium	Semi-bunch
	'Kutamba' No. 1	Tanganyika	Late	Semi-bunch
High resistance	'Kapwato'	Uganda	Medium	Semi-bunch
	'Mwitunde'	Tanganyika	Medium	Semi-bunch
	'Samaru'	Nigeria	Late	Semi-bunch
	'S. 185'	Uganda	Late	Semi-bunch
	'Wima Bunch'	Tanganyika	Late	Semi-bunch
Medium resistance	'East Indies'	East Indies	Medium	Semi-bunch
	'Hong Kong'	Gold Coast	Medium	Semi-bunch
	'Kano 38'	Nigeria	Late	Spreading-bunch
	'Madi'	Uganda	Late	Spreading semi-bunch
	'Mbambey 24–11'	Senegal	Late	Spreading semi-bunch
	'M.H. 372'	?	Medium	Semi-bunch
	'M.H. 382'	?	Medium	Semi-bunch
	'San Jose No. 3'	Philippines	Late	Spreading semi-bunch
	'T.M.V. 3'	Madras	Late	Runner
	'43G. 68+H'	South Africa	Medium	Semi-bunch
Some resistance	'A. 21'	Belgian Congo	Late	Spreading semi-bunch
	'Amanting'	Gold Coast	Late	Runner
	'Averede'	Gold Coast	Late	Runner
	'B.S. 1'	Uganda	Late	Spreading semi-bunch
	'Local spreading'	Uganda	Late	Spreading semi-bunch
	'Mgongo'	Tanganyika	Late	Semi-bunch
	'S. 723'	Uganda	Late	Spreading semi-bunch
	'T.M.V. 1'	Madras	Medium	Spreading semi-bunch
	'9/K. 38'	?	Late	Semi-bunch

Of these varieties 'Kanyoma' and 'Mwitunde' were selected for detailed study of the characters of resistance. Both varieties have desirable characters of habit and length of season and have given consistently good yields in experiments and large-scale plantings at Nachingwea.

Wilson and Wilson [20] reporting trials of fungicides against Cercospora found 'very little disease on undusted checks of runner varieties, with no visible differences between treatments and very slight yield increases, while big increases were found in "Spanish" in parallel trials'. In the Senegal, Jaubert [12] recommended a schedule of dusting with the time of the first application dependent on the susceptibility of the variety grown. In Nyasaland [25] a 'Perenox' spray controlled Cercospora on the variety 'Gambia' (a short-season bunch with light foliage) giving a yield increase of 70 per cent., but there was no significant increase in the yield of 'Mwitunde'.

This was also the experience on two occasions in Tanganyika when fungicides were used. At Urambo in 1952 [26] a Bordeaux-mixture spray was used on 'Natal Common' and 'Mwitunde' in adjacent experiments, the yield showing a significant difference with the former variety only. At Nachingwea in 1953 sulphur dust was used; the yield differences were not significant but that for 'Mwitunde' was less than half the difference for 'Natal Common'.

	Yield kernels, lb. per acre	
	'Natal Common'	*'Mwitunde'*
URAMBO, 1951 (Bordeaux spray)		
Treated	756	571
Nil	587	496
Significant differences:		
P = 0·05	146	107
P = 0·01	197	145
NACHINGWEA, 1953 (sulphur dust)		
Treated	699	1,058
Nil	534	978
Significant differences:		
P = 0·05	217	310
P = 0·01	341	486

There are, therefore, strong indications from fungicide experiments that the over-all effects of the disease on the yield of 'Natal Common' are much greater than on 'Mwitunde' and similar varieties.

The Nature of Resistance

Observations during the field selection of resistant varieties suggested that, under uniform epidemic conditions, fewer lesions became established on resistant than on susceptible types. It also appeared that lesions were smaller, and did not coalesce so rapidly to cause the large chlorotic and necrotic patches typical of the disease on susceptible varieties.

In an experiment to compare the incidence of lesions on 'Kanyoma', 'Mwitunde', and 'Natal Common' small replicated plots were established in midseason on an isolated site, so that the only source of infection would be a uniform deposition of wind-borne spores. The plots were examined at 2-day intervals and any lesions found were removed before they could sporulate. The recording was continued for 5 weeks. In another experiment under normal infection conditions comparative counts were made of lesions on the petioles and stems of the three varieties. (It is such lesions which cause considerable defoliation as they 'girdle' the petioles and stems.)

Thus, under a uniform spore bombardment more than twice as many lesions were established on 'Natal Common' as on 'Kanyoma', and the petioles and stems appear to resist infection to a high degree. 'Mwitunde' is less resistant but is by no means as susceptible as 'Natal Common'.

Field counts of the incidence of Cercospora were made in the early

stages of the epidemic in 1953. (Lesion counts are impossible later as the lesions become too numerous, and when defoliation begins lesions are lost before sampling.) The counts were on samples of fifty plants at random from parallel strips of 'Kanyoma' and 'Natal Common' separated by a wide strip of 'Kanyoma'. All the leaves, empty nodes (i.e. fallen leaves), and lesions were counted. The results are shown in Fig. 1; on 'Kanyoma' the rapid increase of lesion numbers to epidemic level occurred some 13 days later than on 'Natal Common'. This interval is longer than the incubation period from spore infection to the first appearance of the lesion (10–11 days) and it is concluded that the increase on 'Kanyoma' was caused by the spore inoculum spreading from the large numbers of lesions on 'Natal Common'. On both varieties substantial defoliation commenced 10–15 days after the sudden increase in

Variety	*Lesions per 10 plants in 5 weeks*	*Lesions per petiole*	*Lesions per stem*
		(*means of 100 sampled*)	
'Kanyoma'	11·7	1·4	2·[illegible]
'Mwitunde'	20·8	1·7	2·5
'Natal Common' . . .	24·8	4·6	16·0
Significant differences:			
P = 0·05 . . .	4·0	..	..
P = 0·01 . . .	5·5	..	..

lesion numbers. (It is noteworthy that the semi-bunch 'Kanyoma' forms a larger plant than 'Natal Common' and has about 1½ times as many leaves per plant; thus defoliation expressed as a percentage of total leaves per plant would demonstrate a less severe loss.)

A parallel series of counts was made at another site comparing 'Mwitunde' and 'Natal Common'; in this case the increase of lesions on 'Mwitunde' was only slightly later than on 'Natal Common'. The incidence on adjacent fields of 'Kanyoma' and 'Mwitunde' was studied in 1954; the epidemic build-up was much slower, and although the incidence was greater on 'Mwitunde', on neither variety did the epidemic rise to serious proportions or cause appreciable defoliation.

When both species of Cercospora are found together, the lesions of *C. arachidicola* are larger than those of *C. personata*, but the average lesion size of each species appears smaller on resistant varieties, and the rate of growth of lesions seems slower. To obtain comparative measurements of the lesions of each species on the three varieties under test, 'grab samples' were taken from adjacent plots. The samples included leaves of all ages and from various positions on the plant. The identification of the causal species is fairly simple when the lesions are actively sporulating in humid conditions [2]. The smallest diameter of the central area of each of 120 lesions on each variety was measured with calipers. The mean areas of the lesions of each species were calculated to be: *C. personata* 4·54, 6·94, and $10{\cdot}97 \times 10^{-3}$ sq. in., and *C. arachidicola* 6·08, 10·94, and $16{\cdot}29 \times 10^{-3}$ sq. in., for 'Kanyoma', 'Mwitunde', and 'Natal Common', respectively.

Thus the average lesion of each species on the susceptible 'Natal

Common' is more than double the area of those on 'Kanyoma', 'Mwitunde' being intermediate. These measurements are of the central necrotic parts of the lesions; less severely affected leaf tissue extends in a concentric halo, or, where a lesion includes a main vein, into a whole segment of the leaflet. The effect of major importance in the epidemic build-up is that the larger lesions on a susceptible variety have a correspondingly greater spore production.

The rates of growth of lesions of each species were studied. Test plants were inoculated with a sprayed spore suspension and twenty lesions on each variety measured daily after appearance until leaflet fall ensued. The graphs of the increases in lesion area are presented in Figs. 2 and 3. From the graphs the daily rates of increase are: *C. personata* 0·60, 1·00, and $2{\cdot}45 \times 10^{-3}$ sq. in., and *C. arachidicola* 1·33, 2·00, and $2{\cdot}77 \times 10^{-3}$ sq. in., for 'Kanyoma', 'Mwitunde', and 'Natal Common', respectively.

Since resistance of some degree is invariably associated with dark-green leaf colour, observations were made on the character of the leaf tissues. Sections of leaflets were cut with a razor and the thicknesses of the various tissues measured on a series of four dates at weekly intervals. (All the sections were cut from similar positions of the leaflets.) The data presented for 'Natal Common' show that leaf thickness increases only during the first 2 weeks after opening. When sections from mature leaflets of each variety were compared, it was found that 'Mwitunde' and 'Kanyoma' had much thicker palisade tissues than 'Natal Common'. (The figures are means of ten measurements on each of ten sections in microns.)

Variety	*Week*	*Upper epidermis*	*Palisade tissue*	*Spongy mesophyll*	*Water-storage tissue*	*Lower epidermis*	*Total*
'Natal Common' .	0	24·8	99·4	56·8	42·6	24·8	248·4
	1	24·8	127·8	56·8	49·7	24·8	284·0
	2	24·8	134·9	60·3	53·2	24·8	298·2
'Natal Common' .	3	24·8	131·4	56·8	53·2	24·8	291·1
'Mwitunde' .	3	24·8	152·6	56·8	49·7	24·8	308·8
'Kanyoma' . .	3	24·8	163·3	56·8	53·2	24·8	323·0

The extra thickness of this substantial tissue, which gives the leaves their darker colour, provides at least a partial explanation for the slower rates of lesion growth on these varieties. The rate is dependent on the penetration and parasiting of individual cells and as growth takes place in all three dimensions there will be a slower area expansion with a thicker tissue.

Pool and McKay [27] studied the mechanism of infection of sugar-beet (*Beta vulgaris L.*) by *Cercospora beticola* Sacc. It was found that infection of the leaf took place only through open stomata. Furthermore, there appeared to be a critical size of the stomatal pore to permit entry of the germ tubes: for *C. beticola* no penetration was observed with pore lengths less than 15 μ, rare penetration of pores whose lengths ranged from 15–19 μ, and the great majority were through pores longer than 19 μ. These authors also made observations on the numbers of stomata per unit area on leaves of different ages.

Inoculation experiments were made on plants of 'Mwitunde', using dense suspensions of spores of each Cercospora species in rain-water. The suspensions were applied with a camel-hair brush to the upper and lower leaf surfaces, petioles, or stems, control plants being painted with clean rain-water only. The test plants were 7 weeks old; after inoculation they were kept in a humid chamber for 48 hours in laboratory daylight and then placed outside for a further 14 days. Lesion counts were made at 12, 14, and 16 days after inoculation.

	C. personata			C. arachidicola		
	12 days	*14 days*	*16 days*	*12 days*	*14 days*	*16 days*
Upper epidermis . .	22	22	22	25	28	28
Lower epidermis . .	0	2	2	3	3	3
Petiole . . .	7	10	10	12	13	13
Stem	9	9	9	7	7	7
All controls . . .	0	0	0	0	0	0

It appears that the great majority of leaf infections originate through the upper epidermis. Observations were next made on the germination of conidiospores of each species and the entry of germ-tubes into the host. As before, the upper leaf surfaces of 'Mwitunde' test plants were painted with spore suspensions and kept in a humid atmosphere for 48 hours. Leaflets were then removed and the lower tissues scraped away so as to leave the upper epidermis adequately transparent. Searches for spores were made under miscroscope high power; germ-tube penetrations were found to have occurred through stomata only. Measurements of the penetrated stomata and the lengths of germ-tubes were taken, using a graduated eye-piece.

Aperture length (μ)	*Nos. of stomata penetrated*		*Length of penetrating germ-tube* (μ)	*Frequency*	
	C. personata	C. arachidicola		C. per.	C. arach.
11·7	0	0	1–5	0	0
13·4	3	1	5–10	12	9
15·0	9	12	10–15	15	27
16·7	24	27	15–20	11	22
18·4	19	32	20–25	7	14
20·0	4	11	25–30	9	7
21·7	0	3	30–35	3	3
..	..	..	35–40	2	4
..	..	..	40–45	0	0

During these observations no penetrations were recorded of stomata less than 13·4 μ in length and the great majority of stomata penetrated were over 16·7 μ long. Germ-tube paths were very irregular, and often passed close to small stomata without deviation. Approximately 30 per cent. of germ-tubes achieved penetration, the longest being 38·4 μ. Unsuccessful germ-tubes commonly reached 30–40 μ before growth ceased.

Counts were made of the numbers of stomata on the leaves of the three varieties under study. Strips of epidermis were removed from leaflets 2 weeks after the opening of the leaf; to facilitate the removal of the

strips the leaves were boiled in water for 1 hour, other tissues then being removed by scraping with a scalpel. All the strips were taken from similar positions on the leaflets. Field counts were made on approximately 100 fields at random, under microscope high power, and the aperture length of each of about 100 stomata was measured using a graduated eye-piece. The frequency distribution of apertures is shown in the following table:

Stomata per mm.^{2}

Aperture length (μ)	*'Natal Common'*		*'Mwitunde'*		*'Kanyoma'*	
	Upper epidermis	*Lower epidermis*	*Upper epidermis*	*Lower epidermis*	*Upper epidermis*	*Lower epidermis*
10·0	0	0	0	0	0	0
11·7	0	0	1	0	2	0
13·4	3	0	6	0	34	0
15·0	0	7	23	0	48	3
16·7	60	19	72	2	54	19
18·4	67	25	41	10	10	34
20·0	15	27	5	28	0	35
21·7	0	28	0	56	0	21
23·4	0	19	0	30	0	10
25·0	0	6	0	10	0	4
26·7	0	2	0	4	0	0
28·4	0	0	0	0	0	0
Mean total per mm.^{2}	153·7	133·3	147·3	139·8	148·4	125·8

The data in this table show that although there is no difference between the total numbers of stomata on these varieties, there is a greater frequency of large stomata on the upper epidermis of 'Natal Common' than on 'Mwitunde' and on 'Mwitunde' than on 'Kanyoma'. There appears little difference in the frequencies on the lower epidermis where the stomata are mostly larger.

In the previous observations on the sizes of stomata it was found that the great majority of those penetrated were more than 16·7 μ long. On the upper epidermis of 'Natal Common' 92 per cent. (i.e. 142 per mm.^{2}) of the stomata are 16·7 μ or longer, on 'Mwitunde' 80 per cent. (118 per mm.^{2}), and on 'Kanyoma' 43 per cent. (64 per mm.^{2}). It thus appears that a very probable explanation of the higher infection rates of the more susceptible varieties is their greater frequency of stomata of penetrable size. As infections originating through the lower epidermis of the leaf are rare, the existence of large stomata on this surface of all the varieties is immaterial. Possibly such infections fail as the germ-tube may be unable to parasitize the water-storage tissue adequately for its initial establishment.

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ADDENDUM

The Publishers and Editor much regret that these figures accompanying Mr. J. S. Hemingway's article 'The Resistance of Groundnuts to Cercospora Leafspots' in *E.J.E.A.*, Vol. XXV, No. 97 (Jan. 1957), were inadvertently omitted when the article was printed. They offer profound apologies to the author and to readers for the mistake.

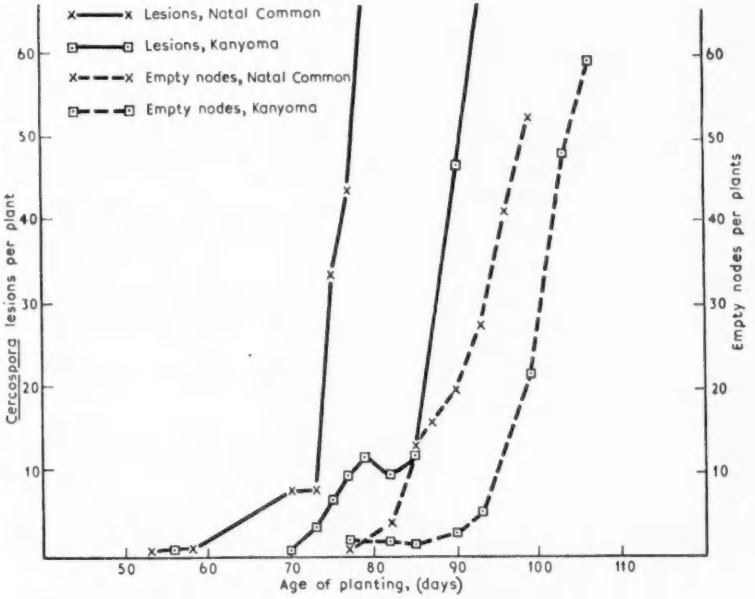

FIG. 1. Incidence of *Cercospora* SPP. and leaf-fall induced on 2 varieties

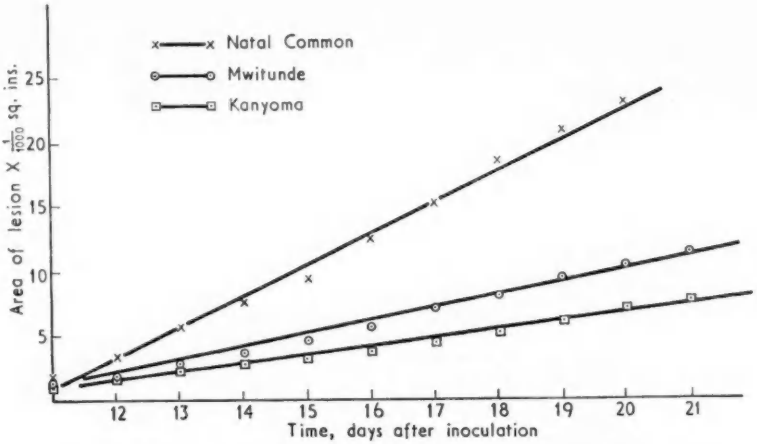

FIG. 2. The growth of lesions of *Cercospora personata* on 3 varieties

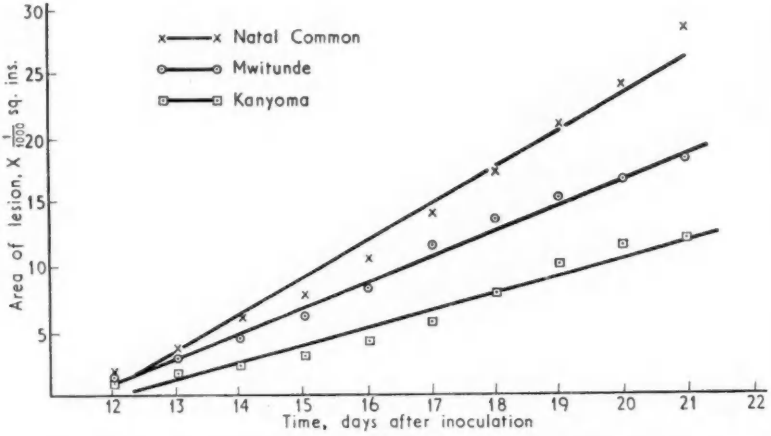

FIG. 3. The growth of lesions of *Cercospora arachidicola* on 3 varieties

THE INFLUENCE OF NITROGEN AND MOISTURE SUPPLY ON THE GROWTH OF PASTURES DURING SUMMER

K. J. MITCHELL

(Grasslands Division, Department of Scientific and Industrial Research, Palmerston North, New Zealand)

Summary

Even with pastures growing under high-fertility conditions, where the nitrogen status of the soil is expected to be high, it is often observed that at the commencement of a period of dry weather, the stimulation of growth of grass in a urine patch is particularly marked. Experiments indicated that this was due to the nitrogen rather than the water content of the urine; and not to any other factor peculiar to urine.

In a grazed pasture of predominantly ryegrass and white clover, the type examined here, the layers of soil near the surface contain the major portion of the available nitrogen. During a period of dry weather it is normally these surface layers which dry-out first. Hence it is suggested that the initial check to the growth of grass under these conditions may occur when adequate moisture is still available from the lower layers of soil, and be due to difficulty in absorbing sufficient nitrogen and possibly other minerals, from the dry surface soil.

In pastures, high levels of production from ryegrass in the spring are frequently followed by a decline in production during the summer. This decline is generally considered to result from lack of soil moisture, or else from a reduction in active leaf growth following flowering [1, 2].

It was observed that under moderately dry summer conditions there could be a large increase in the growth of ryegrass within a urine patch on pastures of dairy farms. This occurred even where the general level of soil fertility, as judged by herbage production, was high.

As Doak's studies [3, 4] have outlined the large changes which occur in the ecological environment of plants within a urine patch compared with the remainder of a pasture, the present series of experiments were initiated as an attempt to assess the relative importance of the content of water, nitrogen, or accessory growth substances in urine, in bringing about the increase in growth of grass during the summer. From the initial results it became apparent that the general issue for study was not any special properties of urine *per se*, but the manner in which soil-nitrogen and moisture status control the growth of ryegrass and clover in a pasture during a warm dry summer.

Experimental

In the Manawatu district the summer of 1953–4 was relatively dry and sunny. Pastures on sandy soils began to turn brown in early December and on many of the silt and clay-loam types drought symptoms appeared in pastures during January. A series of five experiments

[Empire Journ. of Exper. Agric., Vol. 25, No. 97, 1957.]

was laid down on established swards of short-rotation ryegrass and clover, in December and January. These were either at Grasslands Division, D.S.I.R., Palmerston North or adjacent to it.

The average rate of application of fluid which occurs over the area of ground covered by a urination from a cow can be calculated from data published by Doak [4]. It is 0·15 in. and that supplies nitrogen, mainly

TABLE 1. *Particulars of the Treatments, and of Rainfall and Evaporation during each Experiment*

Treatment	*Expt.* 1	*Expt.* 2	*Expt.* 3	*Expt.* 4	*Expt.* 5
(C) Control, untreated	..	..	..	..	..
(W) Water alone, in.	0·15	0·60	0·15	0·30	0·30
(DW) Double water alone, in.	0·30	1·20	0·30	0·60	0·60
(N) Nitrogen alone, as urea, lb.N/acre	440	440	440	440	440
(N+W) Water, in.	0·15	0·60	0·15	0·30	0·30
plus nitrogen as urea, lb. N/acre	440	440	440	440	440
(U) Urine, water, in.	0·15	..	..	..	..
plus nitrogen, lb.N/acre	440	..	..	..	..
(LN) Water, in.	..	0·60	0·15	0·30	0·30
plus light nitrogen, lb.N/acre	..	110 (as urea)	110 (as urea)	110 (as ammonium sulphate)	110 (as urea)
Rainfall during experiment, in.	7·23	1·50	0·50	0·52	0·52
Evaporation from open water surface, in.	6·02	4·46	3·72	3·36	3·36

as urea, at a rate of approximately 440 lb. per acre. As the initial objective of the experiments was to reproduce conditions in a urine patch, the choice of type of nitrogen fertilizer and of rates of application of urine, nitrogen, and water was guided by the above information.

All the five experiments had the following four treatments (in addition to control) in common: *water alone* at *single* rate (treatment W) and *double* rate (treatment D.W.); *nitrogen alone*, at a heavy rate, as urea (treatment N); and *nitrogen plus water* (treatment N+W being a combination of treatments N and W). The remaining treatment, however, varied in the different experiments, thus: in Experiment 1 it was *urine* (treatment U) at a rate equal to that in the average urine patch of a cow; in Experiments 2–5 it was termed *treatment LN* and consisted of *single water* (as in treatments W and N+W) *plus light nitrogen*, i.e. at one-quarter the rate of application which occurs in an average cow-urine patch, the nitrogen being applied as urea in Experiments 2, 3, and 5, and as ammonium sulphate in Experiment 4. Particulars of the treatments, and of rainfall and evaporation during each experiment are set out in Table 1.

The soil types on which the experiments were laid down, and condition of the swards at the commencement of the treatments, were as follows:

Experiments 1–2. Manawatu sandy loam [5]. Pasture sown previous autumn. Nitrogen status, as judged by previous growth, moderate.

Sward mown just previously to a height of 3 in. Experiment 1 commenced (treatment applied) 3 December 1953 and terminated (sward harvested for yield estimation) on 12 January 1954. Experiment 2 went from 8 January 1954 to 4 February 1954.

Experiment 3. Manawatu silt loam [5]. Pasture sown previous autumn. Nitrogen status moderate. Pasture mown to height of 4 in. just before treatments were applied. Experiment commenced 13 January 1954 and terminated 4 February 1954.

Experiments 4–5. Manawatu silt loam. Pasture sown April 1952. Nitrogen status high. Experiments commenced 20 January 1954 and terminated on 10 February 1954. In Experiment 4 the sward was mown to 4 in. and in Experiment 5 down to $\frac{3}{4}$ in. just before treatments were applied.

For all soils used in these experiments the phosphate and potash status were considered to be high. As an additional insurance liberal applications of phosphatic and potassic fertilizers were made during the previous autumn and spring.

In each experiment a randomized block layout was used, with four replicates, each plot measuring 2 × 1 yds. In Experiment 1 two areas of turf each 2 ft. 9 in. × 6 in. were dug up from each plot and from these turfs a count was made in the laboratory of the total plants, plus number of flowering, vegetative, and dead tillers of short-rotation ryegrass present in each treatment. The herbage of short-rotation ryegrass was then weighed. In the other experiments the information concerning yields of herbage, and tiller numbers, was determined from quadrats again 2 ft. 9 in. × 6 in. cut at $\frac{1}{2}$ in. above ground level, harvesting two quadrats per plot.

Soil temperatures were measured with mercury-in-glass thermometers, at depths stated. After placing in position and covering with soil, they were allowed several minutes to each equilibrium. Measurements were made in sunlight at approximately 2 p.m. Check measurements showed that the soil temperature on any given plot varied little during the period of measurement.

Results

Yields of herbage. It can be seen from Fig. 1 that 440 lb. nitrogen per acre, as urea with or without added water, gave a large increase in yield of ryegrass on the sandy loam where 7·23 in. of rainfall fell during the experiment (Expt. 1), but a much smaller increase where rainfall during the experiment was 1·50 in. (Expt. 2). For the pastures on silt loam, receiving approximately 0·50 in. of rain during each experiment, there was a large increase in growth of ryegrass from the application of N to the 4-in. sward, with or without added water, but none from the sward which had been previously mown to $\frac{3}{4}$ in.

In no instance did water alone, even when applied at rates up to eightfold greater than in an average urine patch, give any significant increase in the yield of ryegrass either above control or above the treatment with nitrogen alone.

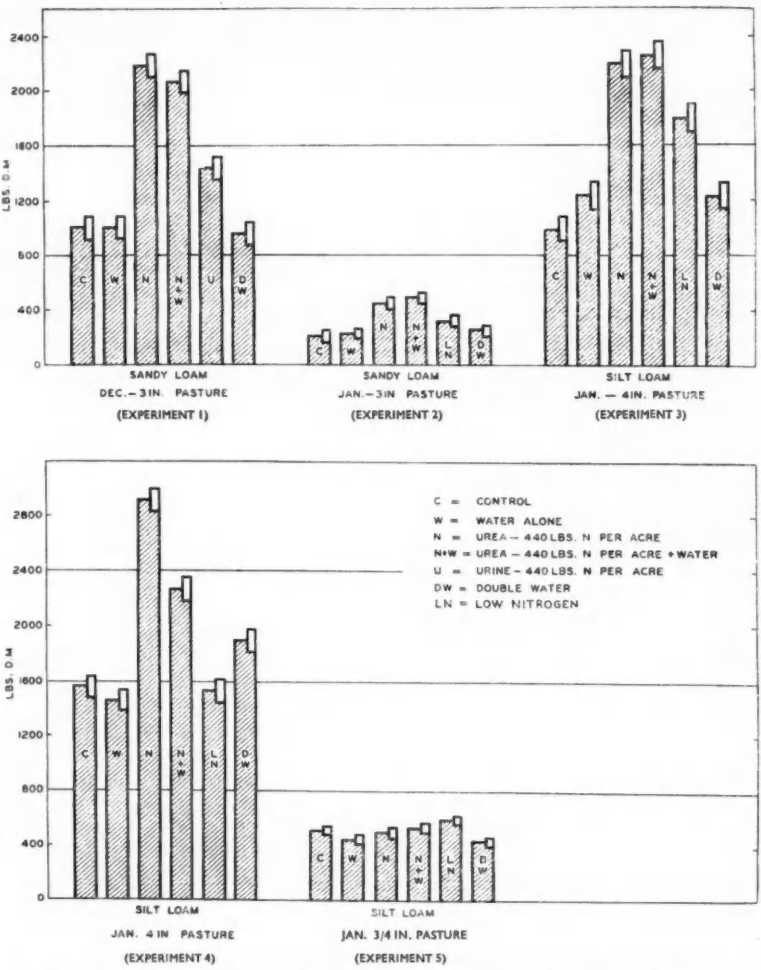

FIG. 1. Yields of short-rotation ryegrass as pounds of dry matter per acre. The standard errors of the mean are indicated at the top of each column.

In Experiment 1 the yields of clover were judged to be relatively low and were not measured. In none of the other experiments was there a clear indication of an increase or decrease in yield of clover resulting from any of the treatments (Table 2). There were apparent indications of a significant increase in clover growth from water, in Experiments 3 and 5, but these indications are negatived either by anomalous results between comparable treatments, or by failure of the F test for the experiment as a whole to reach $P = 0{\cdot}05$ levels of significance.

In Experiment 1 the increase in yield of ryegrass from an application of urine (treatment U) was significantly less than that from urea containing an equal amount of nitrogen, 440 lb. per acre (treatments N and

TABLE 2. *Yield of Clover*

(lb. D.M. per acre)

Treatment	*Expt. 2 Sandy loam. January. 3 in. pasture*	*Expt. 3 Moderate fertility silt loam. January. 4 in. pasture*	*Expt. 4 High fertility silt loam. January. 4 in. pasture*	*Expt. 5 High fertility silt loam. January. ¾ in. pasture*
1. Control	16	646	808	120
2. Water alone	26	962	667	291
3. 440 lb. N/acre	18	609	287	303
4. 440 lb. N/acre+water	35	1,239	548	289
5. 110 lb. N/acre+water	27	526	511	351
6. Double water	40	637	762	350
S.E. of mean, ±	15	168	182	52

N+W). Consequently in the subsequent experiments, the application of urine (Expt. 1, treatment U) was replaced (in treatment LN) by an application of nitrogen at the rate of 110 lb. per acre, as urea (Expts. 2, 3, and 5) or sulphate of ammonia (Expt. 4). This gave a significant increase in ryegrass yield in Experiment 3 only.

TABLE 3. *Tiller and Plant Numbers, Short-rotation Ryegrass on Sandy Loam*

Experiment 1, December 1953

Treatment	*Total plants per sq. ft.*	*Total tillers per plant (live and dead)*
1. Control	77	7·8
2. Water alone	69	8·8
3. Urea 440 lb. N/acre	83	7·4
4. Urea 440 lb. N/acre+water	64	8·0
5. Urine 440 lb. N/acre	62	8·7
6. Double water	72	6·9

Development of tillers. This was examined in considerable detail in Experiment 1 and briefly in Experiments 4 and 5.

In Experiment 1, where it was still possible to recognize individual plants of short-rotation ryegrass within the sward, it was found that differences in treatments had determined, not total number of tillers per plant (Table 3), but the percentage of the tillers which had either formed flowering heads, or were dead (Fig. 2). The percentage of tillers

classified as vegetative, i.e. where there was no visible internode elongation, was not significantly changed by any of the treatments. For treatments receiving nitrogen, in urine or as urea, the percentage of flowering tillers per plant averaged 21·4 per cent., and for treatments without

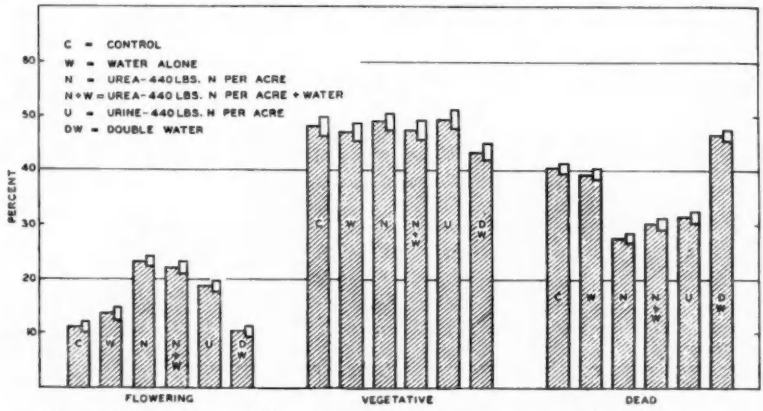

FIG. 2. Classification of the tillers of short-rotation ryegrass from the treatments in Experiment 1. The standard errors of the mean are indicated at the top of each column.

nitrogen 11·8 per cent. The percentage of dead tillers had changed in the reverse direction.

For Experiments 4 and 5, which were alongside each other on an originally uniform pasture, the results of tiller counts from cut samples of grass made from two contrasting treatments, are stated in Table 4.

TABLE 4. *Tiller Numbers per sq. ft. as counted from Samples of cut Herbage from Experiments 4 and 5*

Treatment	*Expt. 4 4 in. pasture*	*Expt. 5 ¾ in. pasture*	*Tiller number in Expt. 5 as percentage of number in Expt. 4*
Control . . .	212	85	40
440 lb. nitrogen + water .	279	123	44

Previous cutting back of the sward to ¾ in. and thus exposing much bare ground, as against leaving the sward at 4 in. where the herbage completely covered the soil surface, gave a 55–60 per cent. reduction in number of tillers present at the end of the trial.

Soil temperatures. January was a fine sunny month. On a representative sunny day soil temperature was measured on several treatments in Experiments 2, 3, and 5. Table 5 sets out the results for the control, and the 440 lb. nitrogen-plus-water treatment in each experiment. These were the extremes.

With Experiment 2, on the sandy loam, there was on the control plots only a sparse cover of dried-out grass and clover. On these plots soil temperatures rose to a mean of 118·5° F. at ¼ in. and 90·5° F. at 3 in. depth. On the plots receiving nitrogen and water there was a cover of green herbage about 3 in. high; the mean temperature at ¼ in. was reduced by 30·0° F. and at 3 in. by 17·5° F.

TABLE 5. *Soil Temperatures at approximately 2 p.m. on 28 January 1954. Each value is the mean of four measurements*

	Expt. 2 Originally 3 in. pasture on sandy loam		*Expt. 4 Originally 4 in. pasture on silt loam*		*Expt. 5 Originally ¾ in. pasture on silt loam*	
Depth of measurement .	¼ in.	3 in.	¼ in.	3 in.	¼ in.	3 in.
Control . . .	118·5° F.	90·5° F.	77·5° F.	67·0° F.	92·0° F.	77·5° F.
440 lb. nitrogen + water .	88·5° F.	73·0° F.	74·5° F.	..	89·0° F.	..

Maximum air temperature for the day 77·5° F.

On the silt loam (Expts. 4 and 5) temperatures were lower under both short and long swards. Where there was a cover of herbage, about 6 in. long at the time of measurement (in the nitrogen plus water treatment on Expt. 4), soil temperature at ¼ in. depth was down to 3° F. below maximum air temperature for the day.

Comparison of urine patch, grass area, and clover area. In the paddock where Experiment 3 was laid down there had been an even establishment of short-rotation ryegrass, but the clover was irregularly distri-

TABLE 6. *Comparison of Clover Area, Grass Area, and Urine Patch. Medium fertility silt loam, January 1954*

	Estimated yield (lb. D.M. per acre)		*Tillers*	
	Short-rotation ryegrass	*Clover-red and white*	*Numbers per sq. ft.*	*Weight per tiller (mg.)*
Grass area . .	1,216±112	107±81	154±20	94·9±16·5
Clover area . .	597±85	1,272±206	140±25	49·8±8·3
Urine patch . .	3,773±371	160±73	338±26	124·9±17·5

buted. Prior to the previous grazing, with dairy stock, clover made little contribution to the total weight of herbage. After that grazing it made vigorous growth but its irregular distribution led to the development of a mosaic in the sward. There was an intermingling of areas with clover dominance and areas where there was ryegrass alone. In the 'grass' areas the ryegrass was not growing vigorously. Its pale yellow-green appearance and low growth contrasted with the tall vigorous dark green of ryegrass in the urine patches in the paddock.

A series of quadrats were cut from sites chosen as representative of a clover area, a grass area, and a urine patch.

A summary of the results from dissection and weighing of the herbage is presented in Table 6. By comparison with a grass area, the weight of

ryegrass had doubled in a urine patch and had been halved in a clover area. Yet in both the clover and grass areas the number of tillers per square foot was virtually the same. The decline in yield of grass in the clover area was due to the development of smaller individual tillers. In the urine patch, with its vigorous growth of ryegrass, tiller numbers were more than doubled.

Discussion

The first issue for elucidation from these experiments was whether the stimulation of ryegrass growth in a urine patch observed in moderately dry summer conditions is due to the water of the urine, its nitrogen, or accessory growth factors, or to an interaction between these. Experiment 1, in which urine gave a significantly lower yield of grass than an equal quantity of nitrogen in urea, indicated the absence of positive stimulation of growth by hormone-like growth factors. From Experiments 1, 2, 3, and 4 it is apparent that the increases in growth were almost wholly due to the nitrogen rather than the water content of the urine.

Further points arise from the results of Experiments 3 and 4. In these the herbage was 4 in. high when the treatments were applied. If allowance is made for the weight of grass present when the treatments commenced, the application of nitrogen at rates equivalent to a urination can be concluded to have approximately trebled the growth of ryegrass. As there was no wilting of the grass, or other direct indication of moisture stress, it can be inferred that, despite the scanty rainfall during these experiments, adequate moisture was available in the soil. However, the extra growth of grass, both roots and herbage, in the plots receiving nitrogen at the rate of 440 lb. per acre, would have used only approximately 50 lb. of that nitrogen. When the rate of application of nitrogen was reduced to 110 lb. per acre, however, the increment in grass growth was much less. That this could be due in part to a large loss of nitrogen as ammonia from the urea [4] is discounted by the similar failure of an equivalent quantity of nitrogen in ammonium sulphate to produce an appreciably greater grass growth (Expt. 4).

These experiments were carried out in a comparatively dry sunny summer. Under such conditions solar radiation would have been relatively high, up to 70 cal./sq. cm./hr. [New Zealand Meteorological Service, unpublished.] A complete cover of herbage will intercept the whole of this and dissipate much of it by evaporation of water from leaves. Accordingly, large quantities of water are required for transpiration. As the greatest proportion of the root system of pasture plants is in the surface layers of the soil [6], it is to be expected that the depletion of soil moisture consequent on that high requirement for transpiration would occur most rapidly in these surface layers. If the rapid depletion continued, the pF of the moisture in those layers where moisture loss is greatest would rise to levels where further intake of water, and consequently of nutrients, by the roots, virtually ceased.

If the sun's radiation strikes the soil surface directly some of it will be dissipated by evaporation of moisture in the surface layers of the

soil and some of it absorbed by the soil. The first will cause a drying of the soil near the surface, and the second a rise in its temperature which will be the greater the drier the soil [7].

As the greater part of the soil-nutrient supplies are in the surface inch or two of the soil [8], it appears that a situation can arise where a plant may be able to draw adequate moisture for growth from roots penetrating to the still moist, but nitrogen-deficient, layers below, yet have its growth checked by being unable to utilize effectively the nitrogen in the drier surface layers. Hence, in these experiments, effective responses to nitrogen occurred only where massive applications were used. In the absence of sufficient rainfall or soil moisture to distribute the nitrogen through the soil, or to allow the root system to operate in the surface layer, it is probable that a low proportion of the nitrogen applied would have reached actively absorbing roots. Part of the response to urea may have been from direct absorption of nitrogen through the foliage.

Where a pasture is defoliated sufficiently to expose a considerable area of bare soil to solar radiation in summer periods in which there is little rain, considerable drying and heating of the surface layers of the soil can occur. This could reinforce the check to growth of an individual tiller resulting from defoliation. It could also slow down the rate at which tillers increase in numbers to give cover over the soil surface, or even cause the death of many tillers. A combination of these factors was probably largely responsible for the absence of any response of ryegrass to nitrogen in Experiment 5 where the pasture had been cut short, despite the large response on the same pasture when left 4 in. long as in Experiment 4.

It was noted in the field that, with the onset of drought conditions, white clover may continue to grow vigorously for some time after growth of ryegrass has slowed down. This is probably due, not to the clover having better access to moisture in the deeper soil, as it is not deeper rooted than ryegrass [6], but to the availability of a supply of nitrogen from root nodules at a time when drying of the surface layers of soil renders the main supply of nitrogen for ryegrass unavailable. The evidence that a tiller of ryegrass made only half as much growth in the presence of clover as in its absence suggests that the roots of the vigorously growing clover were at that time contributing little nitrogen by direct transfer in the soil to stimulate the growth of the grass. Under warm summer conditions legumes may not always symbiotically fix sufficient nitrogen for their own growth requirements [9]. Under these, and certain other environmental conditions, such as described by Willoughby [10], clovers may compete effectively with grasses for supplies of combined nitrogen which become available in the soil. Such conclusions are in no way at variance with the evidence presented by Sears [11] and others, emphasizing the critical importance of the presence of clovers in a New Zealand sward for building up and maintaining the high nitrogen status required for high total production of herbage. Although the vigorous growth of clovers should increase the total quantity of nitrogen in the fertility cycle it appears that significant quantities of nitrogen do not become available to the roots of ryegrass

until the requirements of the clover plants are sated. The sequence of improvement of many New Zealand pastures from a low-producing grass sward deficient in clovers, through a phase of clover dominance to a final balance, at a high level of herbage production, of grass-dominant, clover-subdominant has basically been interpreted in these terms [12].

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THE COMPOSITION AND FERTILITY OF MAIZE SOILS IN NORTHERN RHODESIA

E. PAWSON[1]

Mount Makulu Research Station, Lusaka, Northern Rhodesia

Summary

Seventy maize experiments have been carried out on the Upper Valley soils of Northern Rhodesia. Contrary to former belief, substantial responses to nitrogen were obtained over a wide range of soils. Very large yield increases were obtained by heavy dressings of nitrogen fertilizers in conjunction with increased plant population, but optimum levels require to be established. Response to added nitrogen was not clearly related to total nitrogen or C/N ratio in the soil.

Phosphorus deficiency was less general than was supposed, and substantial responses were confined to one area and soil type. Responses there continued up to high levels of superphosphate application. Superphosphate-phosphate-rock mixture was as effective as superphosphate. Alkali-soluble phosphorus in the soil was correlated to some extent with response to superphosphate.

Response to sulphate (gypsum) has been found at only one site, where a large yield increase was obtained. At present, there is no sign of potassium deficiency.

PRIOR to 1950 a detailed soil survey had not been started in Northern Rhodesia, and the only information available on the nature and distribution of soils was that contained in the Ecological Reports of Trapnell and Clothier [1] and Trapnell [2], and in the Soil-Vegetation Map of Trapnell *et al.* [3]. Quantitative data on the soils were almost non-existent. Partial descriptions were given in the above-mentioned Ecological Reports, but complete profile descriptions and analyses were lacking. Quantitative fertility data were also lacking, although Trapnell and Clothier [1] stated that the soils grouped by them as Upper Valley type were the most promising for general farming. McEwan [4] reported a few field experiments in 1932, but they were confined to one site at Mazabuka and tested only phosphate. McEwan further stated that they were carried out under abnormally unfavourable conditions and, although there was a suggestion of a response to phosphate, the results hardly permitted firm conclusions.

Perhaps due partly to these few results, and partly to opinion in Southern Rhodesia and South Africa, it was widely believed in 1950 that phosphate was always needed for maize in Northern Rhodesia. Presumably due to influence from the same countries, it was also assumed that the application of nitrogen was of no value, except in the form of small quantities incorporated in starter mixtures. There appeared to be no information about the potassium status of the soils, but potassium fertilizers were also being included in local maize mixtures.

The present studies were undertaken to test these assumptions, and to obtain authentic information on the fertility status of the Upper Valley soils, which support nearly all the successful maize and dairy farming in the Territory. During 1950–5, seventy-eight maize experiments were

[1] Present address: Makerere College, Kampala, Uganda.

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laid down in the maize-growing area, the results of which are presented in this paper.

The Soils and their Environment

The Upper Valley soils tend to occur at 2,500 to 3,500 ft. altitude, between the leached Plateau soils of the higher areas and the heavy textured, sometimes saline, Lower Valley soils. Trapnell [2] associates their occurrence at higher altitudes with limestone and basic igneous parent rocks. They are situated mainly in two large blocks totalling

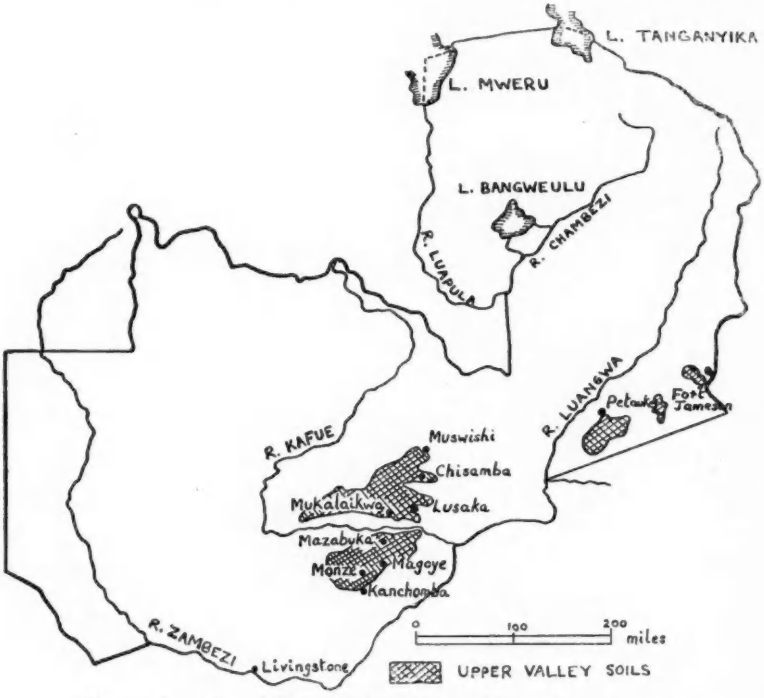

FIG. 1. Location of Upper Valley Soils and Experiment Sites in Northern Rhodesia

about 6,000 square miles, and in a few small patches. Their location [3], and the experimental sites, are shown in Fig. 1. Mean annual rainfall on these soils ranges from about 30 to 37 in., mean maximum temperatures from 83 to 88° F., mean minimum from 58 to 65° F. and absolute maximum from about 100 to 109° F. The rain all falls within the warm season (November to April).

The Upper Valley soils are characterized by either Combretum scrub woodland or Acacia tree-grassland. The two vegetation types corresponded in Trapnell and Clothier's earlier report [1] to a subdivision into

light-textured, light-coloured 'transitional' soils, and heavy-textured, red 'thorn' soils. In the present studies, profiles have been examined and sampled to 6 ft. depth, typifying Trapnell's red 'thorn' soils in the Lusaka and Mazabuka area, the somewhat similar soils in the Petauke area, and the yellowish 'transitional' soils in the Monze area. Samples at 0–8 and 12–24 in. have also been taken from the experiment sites of 1953–5, and mechanical analysis, pH, total nitrogen, organic carbon,[1] and exchangeable bases determined. Soil-phosphorus determinations are referred to later. Although Trapnell's red thorn soils and lighter transitional soils are prominent in the areas studied, a wide range of soils has been found associated with them. Pedological classification of the soil types in the area has not been undertaken but, for the present purpose, they have been divided into the following seven groups.

1. *Red clays in Lusaka area.* 6 in. dark red to brown, clay to clay loam, over somewhat plastic red clay, becoming hard and blocky with depth. Generally 6 ft. or more depth, occasionally limestone near the surface or outcropping.
2. *Red clay loams in Petauke area.* 7 in. dark red to reddish brown, sandy loam to clay loam, over red sandy clay loam. Friable, depth generally more than 6 ft.
3. *Dark brown clays in Chisamba area.* 6 in. dark brown clay, merging gradually down to lighter, more reddish clay.
4. *Dark grey-brown clays, with impeded drainage, in Chisamba area.* 5 in. dark grey-brown clay, with yellowish clay subsoil, with some mottling at depth. Water-table sometimes at 6 ft.
5. *Red loams at Mazabuka, Kanchomba, and Kalichero.* 6 in. reddish brown loam to clay loam, over dark red clay. Friable.
6. *Grey-brown loamy sands in Monze and Magoye area.* 7 in. grey-brown loamy sand, changing abruptly to reddish yellow sandy clay. Depth 6 ft. or more, with some red and yellow mottling at 5–6 ft.
7. *Sands in Muswishi, Mukalaikwa, and Lusaka areas.*

Cation-exchange capacity ranged from 15–25 m.e. per 100 gm. in the first four groups to 3–4 m.e. per 100 gm. in group 7. The top soils were, with very few exceptions, within the pH range 6·2 to 7·0. Group 6 corresponds to Trapnell's 'transitional' soils, and groups 1 and 2 to his 'thorn' soils. The data brought out an important difference between the two latter groups. Group-1 red clays consistently show a rising base status and pH with increasing depth, while group-2 soils show a sharp falling-off in pH and base status as the profile is descended. The latter soils are also noticeably more friable and better drained than those of group 1. Their outstanding productivity has not been accounted for by chemical analysis, and is believed to be due to their better physical properties.

The properties of the Upper Valley soils resemble those of the Shamva and Salisbury series, described by Ellis [5] in Southern Rhodesia, and of the Red Latosols described in the Belgian Congo by Kellogg and Davol [6]. Trapnell *et al.* [3] and van der Merwe [7] have likened them to the

[1] By Bremner's Van-Slyke-Folch method.

Brown Forest Soils and Lateritic Red Earths, respectively, in South Africa, but the data do not support these views.

Experimental Methods

Well-established factorial designs described by Yates [8] were used. Plot size was 1/54 acre. Commercial hybrid seed from Southern Rhodesia and locally selected Hickory King were used but, since they gave responses of the same order they are not differentiated in this account. Except where otherwise stated, a plant population of 9,680 per acre was aimed at. Nitrogen fertilizer was applied as a side-dressing 6 weeks after planting, except where specially indicated, and phosphate was banded in the furrow with the seed. Other fertilizers were broadcast at the time of planting.

Responses to Nitrogen

Results. In three preliminary experiments in 1950, substantial responses to added nitrogen were demonstrated for the first time in Northern Rhodesia. An average yield increase of 700 lb. maize per acre (22 per cent.) was obtained for 200 lb. ammonium sulphate. The results of the subsequent experiments are summarized by seasons in Table 1, and in Table 2 the responses are related to the soil groups already described.

TABLE 1. *Responses to 200 lb. Ammonium Sulphate per acre*

Season	*No. of expts.*	*No. of expts. giving significant responses* (P = 0·05)	*Mean response (all expts.)*		*Mean of significant responses*	
			lb./acre	%	*lb./acre*	%
1951–2	11	9	745	68	860	82
1952–3	15	12	570	33	658	42
1953–4	15	9	727	34	1,025	55
1954–5	26	20	728	49	825	52
Total	67	50	Mean 695	45	831	56

Discussion of results. In group 1, three experiments gave responses to 200 lb. ammonium sulphate of more than 900 lb. maize per acre. On one heavily cropped soil, the response was over 1,700 lb. per acre, provided that the phosphorus deficiency was made good. Group 3 soils responded similarly to those of group 1 on the average, but without any high responses.

Group 2 soils showed much lower responses, but these are about the most productive soils in the Territory, and give high yields with no fertilizers (4,000 lb. or more maize per acre).

Group 4 showed generally poor yields and a poor response to added nitrogen. These soils, however, are subject to waterlogging, with the resulting poor growing conditions.

In group 5, three experiments gave responses of more than 1,000 lb.

TABLE 2. *Responses to 200 lb. Ammonium Sulphate per acre at Different Sites*

Soil group	*No. of expts.*	*No. of expts. giving significant responses (P = 0·05)*	*Mean response (all expts.)*		*Mean of significant responses*	
			lb./acre	%	*lb./acre*	%
1. Lusaka red clays	10	10	728	39	728	39
2. Petauke red clay loams	5	3	471	10	537	11
3. Dark brown clays (Chisamba)	7	5	565	27	878	47
4. Dark grey-brown clays with high water table (Chisamba)	6	3	427	23	441	22
5. Intermediate red clay loams (Mazabuka, &c.)	8	5	852	48	1,182	70
6. Grey-brown loamy sands. (Monze and Magoye)	15	11	574	33	707	44
7. Associated sands (Mukalaikwa, &c.)	16	13	903	78	1,054	94
Total	67	50	..	..	..	..

grain per acre, and on one at Kalichero the response reached 1,700 lb. per acre.

Group 6 gave rather lower responses due, it is thought, to other limiting factors. Four experiments gave responses of 700–800 lb. maize per acre, and one at Monze gave 1,500 lb. per acre.

On the leached sands of group 7, responses were consistently high. Eight experiments showed responses of more than 900 lb. maize per acre, and 5 at Muswishi and Katete gave responses between 1,300 and 2,090 lb. per acre.

It is clear that nitrogen deficiency is widespread, and often severe, in the maize area, and that substantial responses to ammonium sulphate may be obtained over a wide range of soils. This was quite contrary to the belief prevailing in Northern Rhodesia. It may be noted that very many of these experiments followed green manuring with sunnhemp (*Crotolaria juncea*); although this is known to supply nitrogen to the following maize and to improve yields, it evidently does not render the use of ammonium sulphate superfluous.

Table 3 shows the range of total nitrogen and C/N ratio in the different soil groups.

TABLE 3. *Total Nitrogen and* C/N *ratio of Maize Soils*

Soil group	*Total nitrogen* (%)		C/N *ratio*	
	Range	*Mean*	*Range*	*Mean*
1.	0·11–0·16	0·13	11·7–14·0	13·0
2.	0·12–0·14	0·13	15·4–20·0	17·2
3.	0·11–0·14	0·13	14·1–16·9	15·5
4.	0·09–0·13	0·12	11·5–17·5	14·5
5.	0·06–0·13	0·09	10·3–17·6	12·8
6.	0·05–0·09	0·06	10·7–14·0	12·3
7.	0·03–0·05	0·04	11·6–16·8	14·0

The responses to nitrogen are not closely related to the chemical characteristics. High and low responses were obtained over the whole range of C/N ratios, and the correlation coefficient between total soil nitrogen and percentage response to nitrogen was only −0·54. Saunder [9] has reported the use in Southern Rhodesia of empirical factors for calculating nitrogen need from total soil nitrogen, but the present results are valueless for thus predicting response. Although group-2 soils were nearly the least responsive to nitrogen, they had consistently high C/N ratios and contained no more total nitrogen than groups 1 and 3.

Nitrogen in starter fertilizers. By means of local fertilizer mixtures, such as 2 : 15 : 3 and 3 : 13 : 8, it has been common practice in Northern Rhodesia to apply small quantities of nitrogen and potassium to maize at planting time (about 5–7 lb. N per acre). Three experiments tested applications of 37 lb. ammonium sulphate at planting time, but no significant effect was obtained. A further seven experiments compared a starter application of 200 lb. per acre of 19 per cent. superphosphate with an application of 2 : 15 : 3 mixture supplying the same amount of soluble P_2O_5: their effects did not differ significantly. Side-dressing with 200 lb. ammonium sulphate (42 lb. N) per acre was included in all ten experiments, and gave highly significant yield increases of 500 to 2,000 lb. maize per acre. The amounts of nitrogen applied in the starter mixtures might be expected to produce yield increases of only about 140 lb. maize per acre, which would not, in any case, be detected as a significant effect.

Time of application of nitrogen. Rattray [10] has found evidence in Southern Rhodesia that it is more effective to apply ammonium sulphate as a side-dressing 6 weeks after planting, than at planting time. In the present studies, four experiments tested different times of application of nitrogen. A 5 × 5 latin square gave the yields shown in Table 4.

TABLE 4. *Effect of Time of Application of Ammonium Sulphate*

Ammonium sulphate applied	*Mean yield*
	lb./acre
None (control)	2,328
200 lb./acre at planting time	2,914
200 lb./acre 6 weeks after planting	3,351
400 lb./acre 6 weeks after planting	3,665
400 lb./acre split between planting and 6 weeks	3,822

The relative importance of the effects is examined in Table 5.

TABLE 5. *Partitioning of Treatment Sum of Squares from Table 4*

Component	*D/F*	*S.S.*	*M.S.*
All N treatments *v.* control	1	2,318·42	2,318·42†
400 lb. S/A *v.* 200 lb. S/A	1	877·81	877·81†
400 lb. (6 wks.) *v.* 400 lb. (split)	1	28·90	28·90
200 lb. (6 wks.) *v.* 200 lb. (at planting)	1	225·63	225·63*
Treatment total (check)	4	3,450·76	
Error	12	399·28	33·27

† Significant at P = 0·001. * Significant at P = 0·05.

Although most of the effect was due to general response to nitrogen, there is some suggestion of an advantage in late application. In a $3 \times 3 \times 3$ NPT experiment, time of application and its interaction with quantity of nitrogen were both just significant at P = 0·05 (Table 6).

TABLE 6. N × T *Interaction Table*

	Mean yield (lb./acre)		
	T_1 *(at planting)*	T_2 *(6 weeks later)*	T_3 *(split dressing)*
N_1 . .	1,720	1,620	1,340
N_2 . .	1,856	2,182	1,953
Mean . .	1,788	1,901	1,646

The main effect and interaction are shown partitioned in Table 7.

TABLE 7. *Analysis of Treatment Sum of Squares from Table 6*

Component	*D/F*	*S.S.*	*M.S.*
Level of sulphate of ammonia:			
200 lb. *v.* 100 lb.	1	134·48	134·48
Time of application:			
Split dressing *v.* not split	1	24·67	24·67†
6 weeks *v.* planting time	1	5·88	5·88
Interaction:			
Level × splitting	1	10·89	10·89
Level × late or early	1	21·33	21·33*
Treatment sub-total (check)	5	197·25	
Error	14	41·80	2·985

† Significant at P = 0·01 * Significant at P = 0·05.

These results do not confirm the superiority of the 6-weeks' dressing. The other two experiments, at different sites, showed no significant differences between times of application, so that the results as a whole are inconclusive.

Heavy fertilizer dressings and increased plant density. Some of the maize soils had failed to respond to nitrogen, but produced good yields without fertilizer, and it seemed that increased plant populations might be used to obtain very high yields. The generally prevalent plant population in Northern Rhodesia had been about 10,000 per acre, corresponding to 3 ft. × 1 ft. 6 in. spacing: it was believed that 12,000 to 15,000 might be used on very productive soils. It was also thought that other soils might carry increased populations, if ample nitrogen and phosphorus were supplied. It was not expected that rainfall would generally be a limiting factor.

Factorial experiments, involving several levels of plant density, nitrogen and phosphorus, could not be carried out at the time, but an experiment was arranged which would indicate the order of yields likely to be

attained on several soil types. The arrangement consisted of factorial combinations of four levels of ammonium sulphate (maximum 405 lb. per acre) with four levels of superphosphate (maximum 324 lb. per acre),

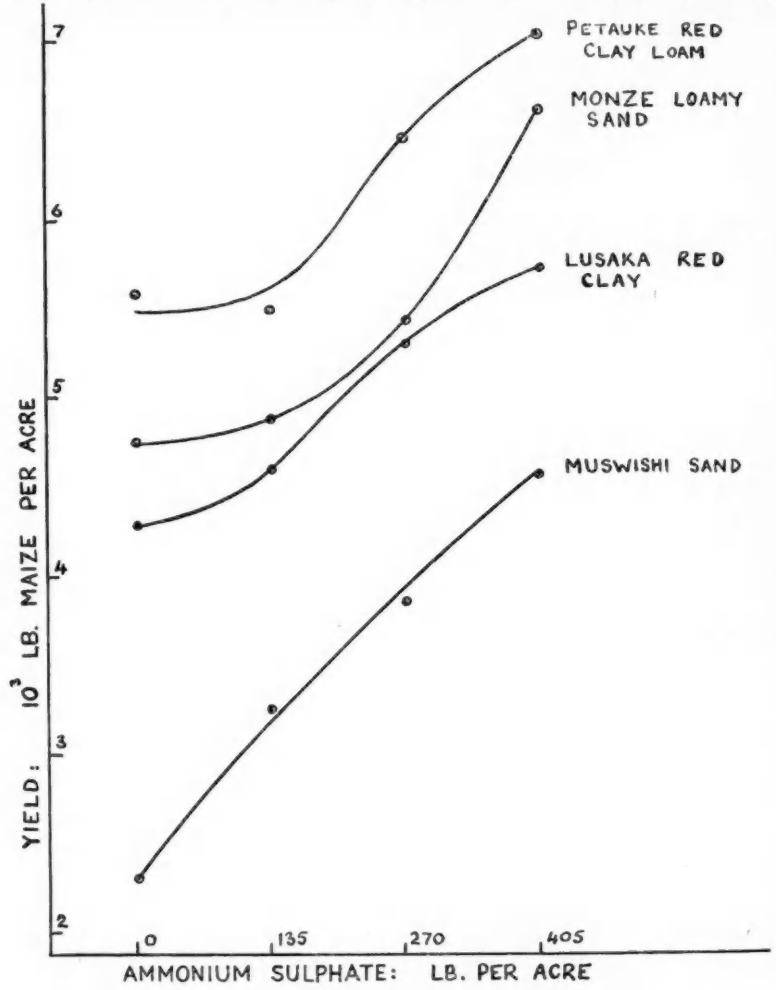

FIG. 2. Yield-Ammonium Sulphate Curves

but with moderate changes of population tied to the nitrogen rates. Thus, N_0 and N_1 were used on a population of 9,700 plants per acre, N_2 on 11,600, and N_3 on 14,500 per acre.

The magnitude of yields obtained aroused immediate interest. In Fig. 2, the yields at these different levels of nitrogen and plant density

are shown for four sites of widely differing fertility. Maximum yields per acre of 7,060 lb. on Petauke red clay loam, 5,740 lb. on Lusaka red clay, 6,630 lb. on Monze loamy sand, and 4,580 lb. on a leached sand at Muswishi were obtained. Such high yields had not previously been approached on such soils in Northern Rhodesia. These figures represent yield increases per acre, due to the combined effect of 405 lb. per acre of ammonium sulphate and a 50 per cent. increase in plant population, of 1,500 lb. (23 per cent.), 1,450 lb. (34 per cent.), 1,870 lb. (39 per cent.), and 2,260 lb. (92 per cent.), respectively. Further experiments confirmed these tendencies, increases of 23, 37, and 200 per cent. being recorded at Petauke, Monze, and Muswishi, respectively. In addition, a measured acre was planted on red clay at Lusaka, using the highest planting and fertilizer rates of the experiment. A total weight of 6,480 lb. of maize was harvested.

It seems likely that, at suitable plant populations, responses may continue up to high levels of ammonium sulphate. The determination of optimum levels of plant density and nitrogen fertilizer awaits the results of the main series of factorial experiments, only recently commenced.

Economics of nitrogen fertilizers. The prices prevailing in Northern Rhodesia were 40 shillings a 200 lb. bag of maize and £32 a short ton of ammonium sulphate. The purchase price of 200 or 400 lb. of ammonium sulphate would therefore need to be offset by a yield increase of 320 or 640 lb. of maize respectively. The results of the present studies show that these increases are likely to be considerably exceeded.

Responses to Phosphate

Results. Sixty-four experiments tested the effect of phosphorus. Except where specially indicated, the fertilizer was superphosphate, containing 19·0 per cent. water-soluble and 20·5 per cent. total P_2O_5. The mean responses to 200 lb. of superphosphate per acre are summarized by seasons in Table 8, and in Table 9 the responses are classified in accordance with the soil groups.

Discussion of results. The results in Table 9 provide a complete contrast to the responses obtained with nitrogen. Whereas a general nitrogen deficiency was found over a wide range of soils, so that 75 per cent. of experiments gave a significant response to nitrogen, only 42 per cent. showed a significant response to phosphate. Furthermore, the main responses to phosphate were centred on one area and soil type, the loamy sands at Monze and Magoye. This was quite contrary to the prevailing belief that all these soils are deficient in phosphorus.

The first five soil groups showed only occasional significant responses, and these were not generally large. On group-1 red clays, responses to 200 lb. superphosphate per acre were 200 to 300 lb. maize per acre, except in experiment no. 78, on a very depleted soil, which gave 760 lb. per acre. Only one soil in group 2 (no. 38) gave a significant response, and this is discussed later. All the responses in groups 3 and 4 were small, those in the latter group suffering from waterlogging. The three significant responses in group 5 were each about 900 lb. maize per acre.

TABLE 8. *Responses to 200 lb. Superphosphate per acre*

Season	*No. of expts.*	*No. of expts. giving significant responses* (P = 0·05)	*Mean response (all expts.)*		*Mean of significant responses*	
			lb./acre	%	*lb./acre*	%
1951–2	11	5	336	21	653	41
1952–3	12	8	406	30	659	59
1953–4	15	4	464	15	972	34
1954–5	26	10	280	15	605	33
Total	64	27	Mean 356	19	733	40

TABLE 9. *Responses to 200 lb. Superphosphate per acre at Different Sites*

Soil group	*No. of expts.*	*No. of expts. giving significant responses* (P = 0·05)	*Mean response (all expts.)*		*Mean of significant responses*	
			lb./acre	%	*lb./acre*	%
1. Lusaka red clays	9	3	220	8	425	23
2. Petauke red clay loams	5	1	261	6	870	21
3. Dark brown clays (Chisamba)	6	2	127	14	424	24
4. Dark grey-brown clays with impeded drainage (Chisamba)	6	3	258	13	324	16
5. Intermediate red clay loams (Mazabuka, &c.)	8	3	435	34	925	77
6. Grey-brown loamy sands (Monze and Magoye)	15	11	695	34	943	45
7. Sands:						
(*a*) Mukalaikwa, Chalimbana	8	4	253	8	445	28
(*b*) Muswishi, Katete	7	0	10	2	..	..
Total	64	27	..	..	..	..

In group 6, the loamy sands at Monze and Magoye present an entirely different picture. About 75 per cent. of the experiments gave a significant response to phosphorus, and the responses were consistantly high. In five experiments, they exceeded 1,000 lb. maize per acre, and in one case reached 1,460 lb. It is clear that this group is subject to a severe phosphorus deficiency.

The sands of group 7 divide sharply into two classes: those at Muswishi and Katete are amply supplied with phosphorus, while some of the Chalimbana (Lusaka) and Mukalaikwa sands gave responses of 300 to 600 lb. per acre.

Significant negative responses to phosphate have been very few. Experiment no. 66 at Monze gave a mean decrease in yield of 277 lb.

per acre for 200 lb. superphosphate, just significant at P = 0·05. That soil was very deficient in nitrogen, giving a 120 per cent. response to 200 lb. of ammonium sulphate per acre, and is further discussed under N × P interaction. The only other instance of a significant depression by phosphorus was in experiment 70, on a highly leached hillside sand at Chalimbana (Lusaka). This gave a yield decrease of 422 lb. maize per acre, significant at P = 0·01. A second experiment at the same site gave a suggestion of a depression. Although extremely deficient in nitrogen, analysis indicates that this soil is also very deficient in phosphorus, and a depression was unexpected. Growth of maize on this sand was still very poor even when both nitrogen and phosphorus were supplied, and it seems likely that there was a multiple deficiency. In these circumstances, the depression might be due to antagonism between the phosphorus or calcium of the superphosphate and another severely limiting element.

Responses to heavier fertilizer dressings. In ten experiments superphosphate was applied at 0, 108, 216, and 324 lb. per acre. The experiments were carried out on red soils of groups 1 and 2, loamy sands of group 6, and sands of group 7 and, as already described under heavy nitrogen fertilizer dressings and increased plant population, they were characterized by high average yields. Even under these conditions, seven of the experiments showed no response to phosphorus, but the two soils at Monze gave large responses. One red soil at Petauke (no. 38) also gave a response at the lower level of superphosphate, but analysis showed that this soil was considerably lower in all nutrients than the usual Petauke red clay loams. Yields for the three responsive soils are shown in Fig. 3, and it seems likely that maize will respond to fairly high levels of phosphorus on the Monze loamy sands. The position of the intermediate points, exhibited by both the phosphate-deficient Monze soils, is interesting, in view of van Garderen's report [11] of the persistent occurrence of a similar phenomenon with numerous phosphorus-deficient soils in South Africa.

N × P *interaction.* In six experiments, there was an N × P interaction of 250 to 650 lb. maize per acre, which either just reached, or just failed to reach, the P = 0·05 level of significance. None of the other experiments showed any approach to a significant interaction. The largest N × P interaction was on experiment 78 on red clay at Lusaka, and has

TABLE 10. *Effects in Three Seasons in Experiment 78*

Season	*Yield with no fertilizer*	*Mean effects (lb./acre)*		
		N	P	N × P *interaction*
1952–3	2,108	708	928	−46
1953–4	1,052	1,156	1,262	+54
1954–5	575	1,072	763	+658

already been mentioned under responses to phosphate. This soil was highly depleted after three successive maize crops, and its decline in yield during the last three seasons is shown in Table 10.

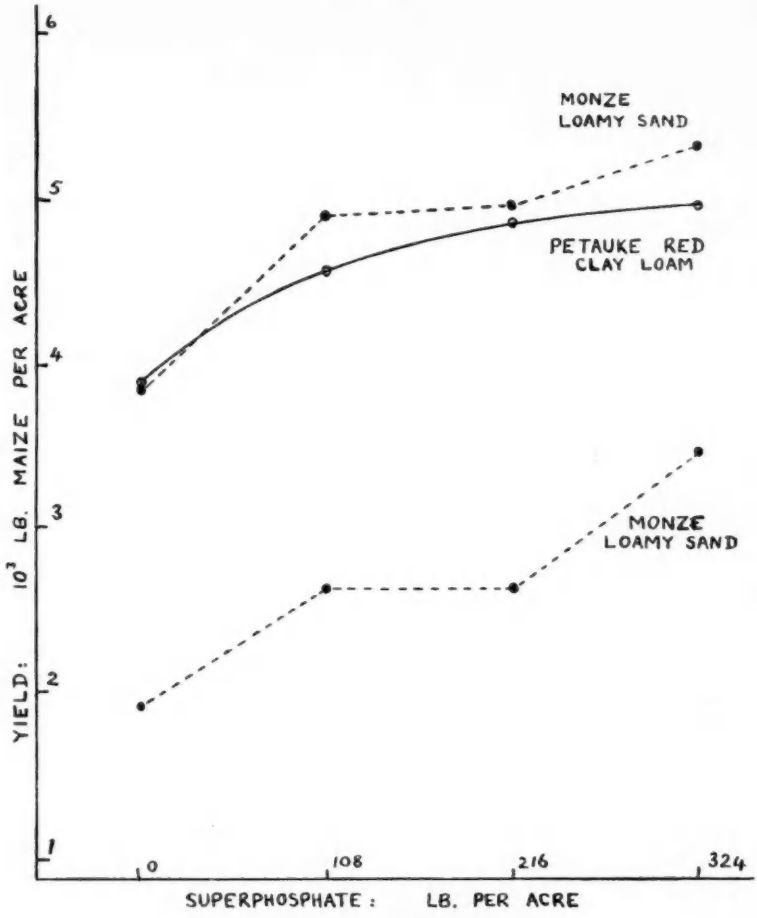

FIG. 3. Yield-Superphosphate Curves

As the soil became depleted, the yield with no fertilizer fell to a very low value, the mean effects of N and P declined and the interaction rose. In experiments 19 at Mazabuka and 26 at Chalimbana (Lusaka), yields were again extremely poor, and the depleted soil showed a significant N × P interaction.

The soil of experiment 66 was unusually well supplied with phosphorus for the Monze area, probably due to a long period of generous use of phosphorus fertilizers. It was, however, acutely deficient in nitrogen, and has already been mentioned as giving a negative response to phosphate. It was the only soil to give a significant negative N × P interaction.

Relation to soil phosphorus. During 1952–3 laboratory attempts to extract phosphorus from these soils were unsuccessful. Acid reagents frequently failed to extract any measurable phosphorus from soils which gave no indication of being deficient in that element. In 1952 difficulties in assessing soil-phosphorus status were reported in Southern Rhodesia by Ellis [12], Saunder and Salmon [13], and McDonald [14]. See also [15].

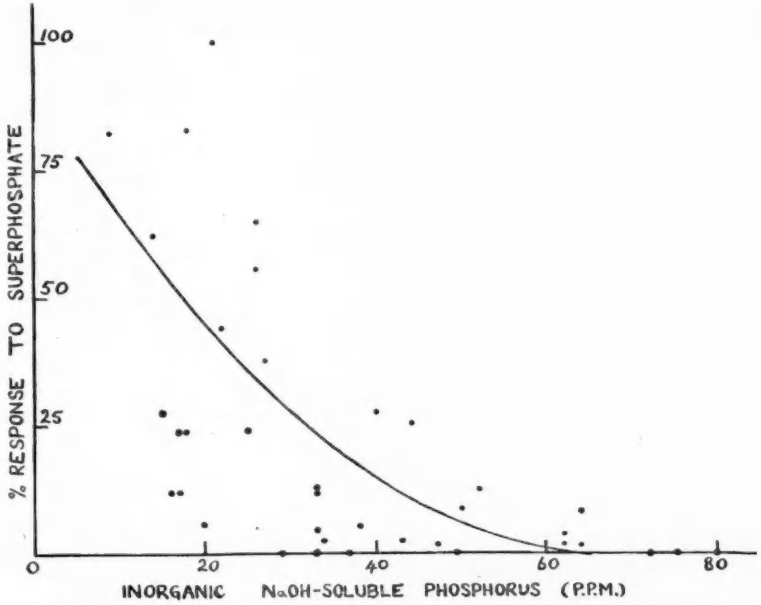

FIG. 4. Correlation between Soil Phosphorus and Percentage Response to Phosphate

The problem was studied in Northern Rhodesia during 1953–5, using phosphorus fractionation and other methods. The acid-soluble portion proved to be a minor fraction of the extractable phosphorus, and did not reflect the phosphorus status, especially in the case of the red soils of groups 1 and 2. The inorganic phosphorus extracted by cold 0·1 N sodium hydroxide was, on the other hand, considerably greater in amount and could, to some extent, be correlated with field results. On the basis of Williams's classification [16], the effective soil phosphorus in these soils seems to be that grouped as 'adsorbed phosphorus, and basic iron and aluminium phosphates'. Gethin Jones [17] reported in 1949 that 0·5 N sodium hydroxide was preferred for phosphorus extractions of red Kenya soils, and in 1954 Saunder [9] stated that extraction with boiling 0·1 N sodium hydroxide gave a good indication of available phosphorus in red clays in Southern Rhodesia.

In Fig. 4, inorganic NaOH-soluble phosphorus is plotted against

percentage response to 200 lb. superphosphate per acre for the whole range of soils, and an approximate negative correlation is apparent (correlation coefficient = −0·61). The quadratic curve of best fit, for regression of percentage response on extracted phosphorus, is also shown: it gives a highly significantly better fit than the linear regression. It is evident that, if the data were used to calibrate the determination of 'available' phosphorus, the scatter may make individual predictions inaccurate. Until more results are available for the separate soil types, this is no more than one might expect.

Several features of the field results fit in with the amounts of inorganic phosphorus extracted by sodium hydroxide. Thus, the figures were high in groups 1 and 2, except for the two responsive soils of experiments 78 and 33, which had values much lower than the average. The group-6 loamy sands had very low alkali-soluble phosphorus, except for the four unresponsive soils (including experiment 66 previously mentioned), which had three times as much as the others. Similarly, the unresponsive group-7 sands at Muswishi and Katete had three times as much NaOH-soluble phosphorus as those at Chalimbana and Mukalaikwa (see Table 9).

Type of phosphate. In 1951, owing to world sulphur shortage, a mixture of superphosphate and phosphate rock was imposed in Northern Rhodesia as a compulsory substitute for 19 per cent. superphosphate. The mixture contained 10 per cent. water-soluble and 26 per cent. total P_2O_5. Twenty experiments were carried out which gave a direct comparison of the two fertilizers, using 200 lb. per acre in each case. In every experiment where superphosphate gave a significant yield increase, the mixture also gave one. Only one experiment showed a significant difference, when the effect of superphosphate was just significantly better than that of the mixture. The mean response to the two fertilizers is shown for all soils, and for soils with less than 30 p.p.m. of inorganic NaOH-soluble phosphorus, in Table 11.

TABLE 11. *Responses to 200 lb. of Super or Mixed Phosphate per acre*

Soil class	*Response to super*	*Response to mixture*
	lb./acre	*lb./acre*
All soils	351·0	376·3
Soils with less than 30 p.p.m. inorganic NaOH-soluble phosphorus . .	452·0	480·9

Under the conditions prevailing in these soils, the two fertilizers appear to be equally effective.

Economics of phosphate fertilizers. The prices prevailing in Northern Rhodesia were 40 shillings a 200 lb. bag of maize, and £15 a short ton of either 19 per cent. superphosphate or superphosphate-phosphate-rock mixture. The purchase price of 200 or 320 lb. per acre of fertilizer would, therefore, need to be offset by a yield increase of 150 or 240 lb. maize per acre, respectively. On the responsive loamy sands at Monze and Magoye, these increases are likely to be greatly exceeded.

Responses to Sulphur

In an early experiment on Lusaka red clay, the application of superphosphate caused a marked darkening in colour of the maize, resembling the effect of a nitrogen fertilizer. It was thought possible that the sulphur in the superphosphate might be influencing the nitrogen status of the plants. Greenwood [18] drew attention to sulphur deficiency for legumes in West Africa, and such deficiency has been reported in Nyasaland soils by Storey and Leach [19] and in East Africa by Beauchamp [20].

An experiment was laid down at ten centres, representing all soil groups except group-7 sands, in which one of the treatments was gypsum (270 lb. per acre), the other three being sodium nitrate, 'triple' superphosphate and muriate of potash. At Kalichero in the Eastern Province, gypsum increased yield from 2,495 to 3,450 lb., i.e. by 955 lb. per acre, significant at $P = 0{\cdot}01$. The effect is assumed to be due to the sulphur and not the calcium, because the soil is neutral and well supplied with exchangeable cations. None of the other experiments gave a significant response to gypsum. It was subsequently shown that application of phosphate (free from sulphate) to the Lusaka soil increased both the uptake of nitrogen, and its percentage in the plant.

Responses to Potash

Thirty-four experiments have included potassium (108 lb. muriate of potash per acre) as a factor. In one experiment, a yield increase of 240 lb. maize per acre was obtained, just significant at $P = 0{\cdot}05$ per cent., while in three others a significant depression was recorded. No others gave a significant effect. So far as maize is concerned, there appears to be no shortage of potassium in these soils. Saunder reports [9] that Southern Rhodesian soils have only begun to show potassium deficiency after prolonged cropping, and he associates deficiency with an exchangeable potassium content of less than about 1 per cent. of the exchange capacity, or 0·12 m.e. per 100 gm. in soils of low exchange capacity. The Northern Rhodesian soils average about 0·5 to 0·9 m.e. per 100 gm., occasional sands going down to 0·1 m.e. At the existing level of cropping, it is considered unnecessary at present to incorporate potassium fertilizers generally, in maize fertilizers in Northern Rhodesia. With greatly increased yields, due to raised levels of plant population and nitrogen fertilizer dressings, the position would need to be reviewed.

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THE EFFECT OF CROP ROTATION ON ROOT-KNOT NEMATODES IN THE GOLD COAST

F. C. PEACOCK

(*University College of the Gold Coast, Achimota*)[1]

Summary

Field experiments were carried out in which different rotations were employed to reduce root-knot eelworm populations, the control being continuous cropping with a host plant. The results showed that the greatest reduction in root-knot followed a cultivated bare fallow during a dry season.

Reduction of the eelworm population by growing an immune crop (groundnut), commonly ascribed to 'starving out' the eelworm, was also highly effective, but trap-cropping with cowpea was not so effective, and was extravagant with seed and labour.

CROP rotation as a means of controlling root-knot nematodes (*Meloidogyne* spp.) depends for its effectiveness on reducing the nematode population, commonly ascribed to 'starving out' the eelworm either by a fallow period or by growing a non-susceptible crop. Recourse may also be had to trap-cropping—growing a suitable host plant (e.g. cowpea) which the eelworm invades and which is then lifted and destroyed before completion of the life-cycle of the pest.

Godfrey and Hoshino [1] under laboratory conditions, and Godfrey and Hagan [2] under field conditions, showed that trap-cropping markedly reduced infestations, to the depth to which the trap-crop roots penetrated during the time taken for second-generation eggs to be produced, but concluded that trap-crops 'were unpromising as an eradication measure, but may be of value in conjunction with other means of nematode control'.

In the Gold Coast the traditional farming system is a shifting cultivation, which is in effect a fallow rotation. The drawback to this rotation is that many of the indigenous weeds, which very quickly colonize the fallowed area, are hosts of the root-knot eelworm [3]. Bare-fallowing, in which weeds are kept down by frequent cultivation, is an improvement on this method, and if carried out during a dry season, with deeper cultivations, a further reduction in eelworm numbers due to desiccation ensues, as has already been shown [4].

Rotations embodying fallow, a non-susceptible crop, and a trap-crop have been compared by the writer in a small-plot field experiment in a market garden at Accra, Gold Coast.

Experimental

The experiment extended over three 2–3 month growing periods. The first two periods constituted courses in the rotation and the third was that in which the indicator crop (tomato) was grown.

Plots were 3×3 yds., with twofold replication in a randomized

[1] Now at Jealott's Hill Research Station, Bracknell, Berks., England.

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block layout. Treatments were basically four in number—fallow, non-host plant (groundnut), trap-crop (cowpea), and control or host plant (tomato), but each of these treatments was followed, in the second season, by all four, giving sixteen treatments in all. Crops were sown with spacings closer than normal in order to reduce error and possibly to magnify small treatment differences. Groundnuts were broadcast at 180 lb./acre giving about 800 plants per plot at 4-in. spacing. Cowpeas were broadcast at 180 lb./acre giving about 1,000 plants per plot at 3-in. spacing. Tomatoes were planted 15 in. apart each way, giving forty-nine plants per plot.

First-season crops were sown in late July. A small number of cowpea plants were lifted after 12 and after 20 days, stained and examined, when no mature nematodes were found; the whole crop was lifted after 24 days, individual plants were again stained and examined, when fully grown females but no matrix or eggs were found. This was considered to be the longest time the crop could safely be left as a trap-crop. Cowpeas were sown again, in mid-August, and lifted after 21 days; their third and final sowing was in mid-September and they were lifted after 23 days. First-season groundnuts were lifted after 10 weeks—examination of stained roots showed no root-knot eelworms. First-season tomatoes were lifted 11 weeks after planting and the roots were graded for degree of root-knotting, on a scale of 1–10, giving plot-mean gradings varying from 4·8 to 6·2, which was considered to indicate a reasonably uniform heavy infestation. Soil temperatures ranged from 25 to 30° C.

The plots were then forked over carefully, pieces of root being removed, and the second-season crops were sown (mid-October). Cowpeas were removed after 23 days, and subsequently two further sowings were made, the crops being removed at 22 days and 24 days after sowing, respectively. Groundnuts and tomatoes were lifted 11½ weeks after sowing.

The plots were again forked over and the indicator tomato crop sown at the end of January 1956. Tomatoes were lifted and graded for degree of root-knotting in mid-March (7½ weeks after planting). Soil temperatures varied between 33 and 28° C.

Results

Results are presented in Tables 1 and 2. The cultivated-fallow treatment was undoubtedly the most effective, but was less so when applied during July–October than when carried out during October–January (a dry season in Accra). This is in agreement with previous work [4].

The non-host-crop treatment (groundnut) came next in effectiveness in reducing root-knot infestations, and would probably be the most attractive from a practical point of view (where *M. incognita* var. *acrita* is the species involved), requiring least attention.

Cowpea as a trap-crop, under the conditions of this experiment, was quite effective, but it is unlikely that this degree of effectiveness, demanding a high seed-rate and much labour, would be achieved under farming conditions.

TABLE 1. *Effect of Crop Rotations on the Survival of Root-knot Eelworm. Accra, 1955/6*

Rotation		Observations on 3rd-season indicator crop (tomato)				
		After 2 weeks	After 7½ weeks			
1st season	2nd season	Grading for vigour Scale 1–10	Mean number of plants	Mean number of fruits	Mean height in inches	Mean root-knot grading Scale 1–10
Host	Host	7·6	18	0·1	17	6·8
Host	Fallow	9·5	19	1·2	25	3·1
Host	Trap-crop	8·7	19	0·9	25	4·1
Host	Non-host	9·4	19	0·4	21	3·7
Fallow	Host	6·2	11	0·5	15	5·9
Fallow	Fallow	8·6	19	1·5	23	1·7
Fallow	Trap-crop	8·6	19	0·9	23	3·2
Fallow	Non-host	8·7	17	1·4	22	1·6
Trap-crop	Host	7·7	16	0·2	19	7·1
Trap-crop	Fallow	8·8	17	1·3	21	1·4
Trap-crop	Trap-crop	8·2	20	1·1	22	2·4
Trap-crop	Non-host	9·1	19	1·1	24	2·4
Non-host	Host	8·6	16	0·0	18	7·7
Non-host	Fallow	9·5	20	2·8	26	1·6
Non-host	Trap-crop	9·4	19	0·9	21	2·8
Non-host	Non-host	8·8	18	1·8	23	2·2
General mean		8·6 ±0·6				3·6 ±0·7
Significant difference: P = 0·05		1·7				2·2
P = 0·01		2·4				3·0

TABLE 2. *Statistical Significance of Second-season Effects*

Treatment	Host	Fallow	Trap-crop	Non-host
Mean root-knot grading . .	6·9	1·9	3·2	2·5

S.E. of means, ±0·4
Significant difference: P = 0·05, 1·1
P = 0·01, 1·5

Discussion

Marked visible treatment effects had developed on the indicator tomato plants by the end of the second week after planting. Grading for vigour (Table 1) showed these differences to be significant, but before a photographic record could be obtained a heavy rainstorm beat down the plants. Subsequent growth led to a multiplicity of stems rather than an increase in height, so that differences recorded at the end of the growing period were not great.

Statistical analysis of root-knot gradings showed treatment effects to be highly significant (P = 0·01). When first- and second-season

effects and interaction were computed, it was found that first-season effects and interaction were not significant, whilst second-season effects were highly significant ($P = 0{\cdot}01$).

Analysis of second-season effects showed that fallow, trap-crop, and non-host-crop treatments had all led to a significant reduction in root-knot severity. Treatments in order of effectiveness were: (1) fallow, (2) non-host, (3) trap-crop. The difference between fallow and trap-crop treatments was significant at the $P = 0{\cdot}05$ level, that between fallow and non-host, and non-host and trap-crop did not reach significance.

Numbers and height of plants and numbers of fruits were not analysed, but are included in Table 1 to show that beneficial effects against root-knot were not offset by any lack of vigour in the plants.

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THE EFFECT OF CHEMICAL TREATMENTS ON ROOT-KNOT NEMATODES IN THE GOLD COAST

F. C. PEACOCK

(*University College of the Gold Coast, Achimota*)[1]

Summary

Chemical control of root-knot eelworm in the Gold Coast by means of fertilizers was unsuccessful, although in one field experiment two top-dressings of ammonium sulphate each of 1 cwt./acre gave a small but significant reduction in root-knot on tomatoes. Calcium cyanamide and urea, which had shown promise in pot tests, were ineffective in the field, as also were muriate of potash and superphosphate.

Soil injections with DD-mixture, ethylene dibromide, and an experimental compound, tetrachlorobutadiene (crude), all gave excellent control of eelworm on tomatoes under field conditions. With DD-mixture, only the crop immediately following the injection was protected, but ethylene dibromide and tetrachlorobutadiene showed a residual effect on a second susceptible crop.

THIS paper is in two parts, dealing respectively with the effect of fertilizers and of fumigants on root-knot nematodes (*Meloidogyne* spp.).

PART I. FERTILIZERS

The nematicidal effect of ammonia has long been known. Filipjev and Stekhoven [1] stated 'Schoevers [2] has used it with good success against the root-knot of tomatoes, using a mixture of ammonium sulphate and lime which lets escape free ammonia in the soil'.

More recently Hurst and Triffitt [3] working with urea and with calcium cyanamide, which yield ammonia on decomposition in certain soils, and Hurst and Franklin [4] and Edwards [5] working with calcium cyanamide, reported partial control of the potato-root eelworm *Heterodera rostochiensis* Woll., but the treatments have not been developed for commercial use.

In a field experiment at Accra, Gold Coast, in which the effect of fertilizers on root-knot eelworm was studied, a small but highly significant benefit followed the use of ammonium sulphate given as two top-dressings each of 1 cwt./acre. Further field and pot experiments were carried out with ammonium sulphate, urea, and calcium cyanamide.

Pot Experiments

Methods and experimental details. Root-knot infested soil was thoroughly mixed, and the fertilizer treatments incorporated with it in a churn-type mixing-drum. There were three rates of application for each fertilizer and a control. Comparison was on the equal-nitrogen basis, there being grounds for supposing that any nematicidal effect would be due to the formation of free ammonia on decomposition in the soil. The experi-

[1] Now at Jealott's Hill Research Station, Bracknell, Berks., England.

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ments were carried out in 3-inch pots, with fivefold replication. The pots were planted with tomatoes, and subsequently the plants were lifted, washed free of soil, and root-knots counted. Height and weight of plants were recorded.

Experiment 1. Ammonium sulphate and urea in the pure form and calcium cyanamide (technical grade) were compared. It was originally intended also to include an ammonium sulphate top-dressing superimposed later on the highest rate of application of each chemical, but this was abandoned when phytotoxic symptoms appeared in the plants, so that the highest rate of each chemical had, finally, 10 replicates.

The tomatoes were planted 3 days after soil treatment, but this proved to be too soon, severe phytotoxicity occurring. The pots were replanted 9 days after treatment, and the plants were allowed to grow for 22 days before removal for examination.

Experiment 2. Commercial ammonium sulphate, urea (technical grade), and calcium cyanamide as an oiled powder, and in the form of granules, were compared.

The tomatoes were planted 10 days after soil treatment. No replanting was necessary, and the plants were allowed to grow for 30 days before removal.

TABLE 1. *Effect on Root-knot Production of Certain Nitrogenous Fertilizers. Pot Experiments*

Treatment	*Rate cwt./acre*	*No. of knots per plant* — *Means of 5 replicates, except where stated*	
		Expt. 1	*Expt. 2*
Control	nil	66	96
Ammonium sulphate	2·0	78	110
	4·0	27	87
	8·0	10*	94
Calcium cyanamide dust	1·2	101	..
	2·0	..	157
	2·4	44	..
	4·0	..	61
	4·8	30*	..
	8·0	..	nil
Calcium cyanamide granules	2·0	..	63
	4·0	..	80
	8·0	..	24
Urea	0·9	3	43
	1·8	nil	nil
	3·6	nil*	nil

* Means of 10 replicates.

Results. These are shown in Table 1. Ammonium sulphate effectively reduced the number of root-knots in Expt. 1 at 4–8 cwt./acre. At 8 cwt./acre it was slightly phytotoxic. In Expt. 2 it was not effective.

Urea was highly effective at 0·9–1·8 cwt./acre; at 1·8 cwt./acre it was somewhat phytotoxic. Calcium cyanamide dust, at 4–8 cwt./acre, was highly effective, and was not phytotoxic; the granules were much less effective, and were slightly phytotoxic.

Field Experiments

Methods and experimental details. Fertilizers were broadcast and forked into the plots, with the exception of ammonium sulphate in Expt. 3, in which it was applied some time after planting, as a top-dressing.

After an interval necessitated by possible phytotoxic effects of the treatments, the plots were planted with tomatoes. After a suitable growing period the plants were lifted and the roots graded (scale of 1–10) for severity of galling; height and root-weight were also recorded.

Experiment 3. This experiment examined the effects of nitrogen, phosphorus, and potassium in the form of ammonium sulphate, superphosphate, and muriate of potash each at one rate of application, in all possible combinations, in a 3-factor layout with three replicates. Plot size was 3 × 4 yards. Superphosphate was applied at 4 cwt./acre and muriate of potash at 1 cwt./acre. Tomatoes were planted 1 week later on all plots, each plant being set in a double-handful of compost to give it a good start. The two top-dressings of ammonium sulphate each at 1 cwt./acre were applied 20 and 32 days after planting respectively.

No differences in height or general vigour were noted during the growing period; fruit formation was almost negligible, due to blossom-drop, probably caused by high temperatures (75–95° F. minimum and maximum shade temperatures; in the open field over 100° F.; soil temperature at 6 in. depth was up to 35° C.). Plants were lifted 10 weeks after planting, when height, root-weight, and root-knot grading were recorded.

Experiment 4. Ammonium sulphate at 2–8 cwt./acre was compared with urea at 0·9–7·2 cwt./acre, with four replicates in a randomized block layout. Plot size was 1½ × 3 yards, with 18-in. paths between plots.

After application of the fertilizers, the plots were watered lightly and tomatoes were planted 4 weeks later, twelve to a plot. The plants were grown for 7 weeks, then lifted for examination. Soil temperatures at 6-in. depth varied from 33° C. at the time of soil treatment down to 28° C.

Experiment 5. Ammonium sulphate at 2–6 cwt./acre, urea at 0·9–2·7 cwt./acre, and calcium cyanamide at 4·7–7·0 cwt./acre were compared, with four replicates in a randomized block layout. Plot size was 1½ × 3 yds. Tomatoes were planted 3 weeks after soil treatment, and examined 6½ weeks later. Soil temperatures at 6-in. depth varied from 33° down to 28° C.

Experiment 6. Calcium cyanamide granules at 4 cwt./acre were compared with calcium cyanamide dust at 2–6 cwt./acre with six replicates in a randomized block layout. Plot size was 2 × 2 yards with 18-in. paths between plots.

Tomatoes were planted 6 days after soil treatment and lifted 5 weeks later for examination. Soil temperatures were from 31° down to 28° C.

Results. These are summarized in Tables 2 and 3. In Experiment 3 a small but highly significant reduction in the severity of attack on tomatoes was associated with ammonium sulphate applied as two top-dressings each of 1 cwt./acre, alone and in combination with superphosphate and/or muriate of potash. No beneficial effect followed the application of superphosphate and/or muriate of potash before planting, although Oteifa [6] suggested that root-knot damage may be reduced by increasing the level of potassium supplied to the plant.

In Experiments 4, 5, and 6 pre-planting treatments of 2–8 cwt./acre ammonium sulphate, 0·9–7·2 cwt./acre urea, and 2–7 cwt./acre calcium cyanamide proved ineffective in reducing root-knot on tomatoes.

Discussion

The results of field Experiment 3, in which the effects of fertilizers containing the three major plant nutrients were compared, suggested that a reduction in root-knot severity in the light sandy soil studied might follow the use of nitrogenous fertilizers. Pot experiments with three such compounds—ammonium sulphate, urea, and calcium cyanamide, generally supported this supposition, and further field experiments with these fertilizers were therefore undertaken. With the possible exception of urea (2·7 cwt./acre) in Experiment 5, however, none of the treatments was effective in reducing root-knot infestations on tomato in these further experiments. No explanation can be offered to account for the lack of field response to what, in pot tests, were apparently highly promising treatments.

PART II. FUMIGANTS

Fumigants which have given promising results against soil-inhabiting eelworms are certain isothiocyanates [7, 8], chlorpicrin, dichloropropene-dichloropropane (DD) mixture, ethylene dichloride, ethylene dibromide, methyl bromide, and chlorobromopropane [9, 10, 11, 12], and recently 1 : 2-dibromo-3-chloropropane [13]. Most of these compounds have disadvantages such as high cost, injurious residues, phytotoxicity, and toxicity to people working with them.

The use of soil fumigants to control root-knot eelworm in the Gold Coast is likely to be limited, by cost and application hazards, to experimental stations. Nevertheless, three of the cheaper and less toxic fumigants were tested in two field experiments at Abessey and Accra.

Methods and experimental details. In each experiment ethylene dibromide, dichloropropene-dichloropropane (DD) mixture, and an experimental compound, tetrachlorobutadiene (crude), were injected at 14-in. centres by means of the Shell DD-injector gun, which was first calibrated to deliver approximately the required dosage; the application rate actually used was afterwards determined. Injection holes were closed by treading; a water seal was applied at one site only. Fourteen

TABLE 2. *Effect on Root-knot Production of* N, P, *and* K *Singly and in Combination. Experiment 3*

Treatments in order of root-knot grading		*Rate cwt./acre*	*Mean root-knot grading (Scale 1–10)*	
NPK	Ammonium sulphate Superphosphate Muriate of potash	2 4 1	4·3	Mean of treatments containing N: 4·7
NP	Ammonium sulphate Superphosphate	2 4	4·7	
N	Ammonium sulphate	2	4·8	
NK	Ammonium sulphate Muriate of potash	2 1	5·0	
O	Control	..	5·4	Mean of treatments containing no N: 6·1
PK	Superphosphate Muriate of potash	4 1	6·0	
P	Superphosphate	4	6·1	
K	Muriate of potash	1	6·8	
			SE ±0·6	Difference significant at P = 0·01

TABLE 3. *Effect of Nitrogenous Fertilizers on Root-knot Production. Experiments 4, 5, 6*

Treatment	*Rate cwt./acre*	*Mean root-knot grading (Scale 1–10)*		
		Expt. 4: means of 4 replicates	*Expt. 5: means of 4 replicates*	*Expt. 6: means of 6 replicates*
Control	0·0	2·9	2·3	3·9
Ammonium sulphate	2·0	3·7	2·4	..
	4·0	2·5	2·4	..
	6·0	..	3·6	..
	8·0	3·6	..	..
Urea	0·9	3·1	3·4	..
	1·8	2·8	2·7	..
	2·7	..	1·4	..
	3·6	2·4	..	..
	7·2	2·8	..	..
Calcium cyanamide dust	2·0	..	..	4·9
	4·0	..	..	4·6
	4·7	..	1·8	..
	6·0	..	..	4·4
	7·0	..	3·3	..
Calcium cyanamide granules	4·0	..	..	4·3

days after injection the soil was loosened with a fork or hoe, and tomatoes were planted 3 weeks (Expt. 7) or 5 weeks (Expt. 8) after soil treatment.

Experiment 7. Accra. In this experiment the control and DD-mixture treatments were replicated four times; ethylene dibromide and tetrachlorobutadiene (crude) treatments were replicated twice. Plot size was 4½ yards by 7 rows (Block A) or 5 rows (Block B). Rows were 28 in. apart. The soil was injected at 14-in. centres on 20 October 1954 and a water seal applied immediately.

Plant populations were counted at 14 days and 5 weeks after planting, when the plants were also graded for phytotoxic effects; a final count was taken 10 weeks after planting, when roots were dug, examined, and graded for degree of knotting. Soil temperatures ranged from 32° C. at the time of injection down to 29° C. Immediately after lifting the tomatoes in this experiment, the plots were forked over, and tomatoes again planted in the same rows, on 18 January 1955. These were dug and examined 9 weeks later.

Experiment 8. Abessey. Treatments in this experiment were replicated five times; plots were 5 yards by 1 row with a 'buffer' row (28 in.) between plots. Soil was injected at 14-in. centres on 1 November 1954, but it was not possible to seal the area with water.

Plant populations were counted at 10 days and 21 days after planting, and a final count was taken 7 weeks after planting. At 10 and 21 days the plants were graded for phytotoxic effects and the gaps were replanted. Seven weeks after planting the roots were graded for degree of knotting. Soil temperatures during the experiment varied from 29° to 32° C. (32° C. at the time of injection).

Results. These are presented in Tables 4 and 5 and summarized below. Plant counts and gradings showed tetrachlorobutadiene (crude) to have been phytotoxic in both trials, with slow recovery of the plants from its effects. Ethylene dibromide at the top rate of application was somewhat phytotoxic, but plants quickly recovered. DD-mixture was slightly phytotoxic at Abessey but not at Accra, and plants quickly recovered.

Root-knot gradings showed that a high degree of control of eelworm was achieved in both trials by all three chemicals. Tetrachlorobutadiene and ethylene dibromide were rather less effective than DD-mixture at Abessey, but rather more effective at Accra.

The 'follow-up' of Experiment 7 (Table 4) showed that at Accra DD-mixture lost its effectiveness in under 22 weeks. The lower rate (14·6 gall./acre) of ethylene dibromide also gave ineffective control. The top rate (26·0 gall./acre) of ethylene dibromide, and tetrachlorobutadiene at both rates (16·8 and 24·9 gall./acre), gave persistent effective control.

Discussion.

Highly effective control of root-knot eelworm was obtained with the three compounds tested. It is also interesting to compare the phytotoxicity of these chemicals in the two experiments. The soils at the two sites, Abessey and Accra, were similar (pH 7·0, clay fraction 16–17 per cent.), but rainfall at the time of treatment and after was very

TABLE 4. *Effect of Soil Fumigants on Root-knot Infestations on Tomato. Experiment 7. Accra, 1954*

Treatment	*gall./acre*	*c.c./injection*	*Plant population counts. Mean number of plants per plot after . . . weeks*			*Growth marks (Scale 1–10). 10 marks for normal healthy plant; after . . . weeks*		*Mean root-knot grading (Scale 1–10). 10 marks where all roots completely knotted*	
			2	5	10	2	5	*Observations after 10 weeks*	*Second crop observations after 9 weeks (i.e. 22 weeks after injection)*
Control	..	..	30·0	25·3	21·3	8·0	9·1	4·1	3·4
DD-mixture	23·4	3·57	30·0	25·8	24·0	8·0	9·3	1·3	2·8
Tetrachlorobutadiene (crude)	16·8 24·9	2·56 3·79	30·0 30·0	22·0 24·0	21·0 20·0	7·3 7·2	8·4 8·2	1·1 1·1	1·2 1·0
Ethylene dibromide: undiluted 50% in kerosene	14·6 26·0	2·23 3·96	30·0 30·0	25·5 25·0	21·5 21·5	7·8 7·6	8·8 9·2	1·0 1·0	1·7 1·2

Note. It was not possible to replace plants which died.

TABLE 5. *Effect of Soil Fumigants on Root-knot Infestations on Tomato. Experiment 8. Abessey, 1954*

Treatment	*gall./acre*	*c.c./injection*	*Plant population counts. Mean number of plants per plot after . . . weeks*				*Growth marks (Scale 1–10). 10 marks for normal healthy plant; after . . . weeks*		*Mean root-knot grading (Scale 1–10). 10 marks where all roots completely knotted; after 7 weeks*
			1½	3		7	1½	3	
Control	..	..	5·5	4·8	missing plants replaced	3·9	9·2	9·6	3·2
DD-mixture	7·7	1·35	5·4	4·2		4·2	8·9	9·6	1·3
	17·8	3·32	6·0	5·2		4·4	8·5	9·2	1·1
Tetrachlorobutadiene (crude)	8·2	1·42	5·6	4·8		4·8	8·3	8·0	1·3
	18·6	3·29	5·2	4·2		5·0	7·0	8·1	1·4
Ethylene dibromide: undiluted	8·6	1·52	5·8	5·0		4·0	9·6	9·7	1·8
50% in kerosene	19·1	3·39	5·4	3·6		3·4	8·5	9·7	1·5

different. At Accra, November rainfall was 2·49 in.; the rate of application of the chemicals was higher than at Abessey; plots were watered after treatment; and tomatoes were planted 3 weeks after treatment. At Abessey, November rainfall was 10·18 in.; rate of application of the chemicals was lower; plots were not watered; tomatoes were planted 5 weeks after treatment; yet phytotoxic effects were slightly more marked at Abessey than at Accra. Optimum rates of application of fumigants, and the interval between soil treatment and planting, should therefore be estimated with due regard to expected rainfall.

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CHANGES IN A SULPHIDE-CONTAINING MANGROVE SOIL ON DRYING AND THEIR EFFECT UPON THE SUITABILITY OF THE SOIL FOR THE GROWTH OF RICE

T. E. TOMLINSON

(*Soil Chemist, West African Rice Research Station, Rokupr, Sierra Leone*)

Summary

A sample of sulphide-containing mangrove soil was dried in air, when its pH value fell. Sub-samples of the soil were withdrawn at different stages of drying and in this way a series of soils of different pH values was obtained. Rice seedlings were transplanted into such a series of soils in pots and their subsequent growth was observed.

The seedlings made good growth if the pH value of the soil was between 7 and 5. If the value was between 5 and 4, the seedlings survived but tillering was restricted. If the value was between 4 and 3, some seedlings died and those surviving were stunted. Below a pH value of 3, all seedlings died.

The 'availability' of calcium, magnesium, manganese, iron, aluminium, and phosphate in the soils was determined by extraction with ammonium acetate. A marked increase of extractable iron and aluminium between pH 5·5 and 4·0 was observed. The restriction or failure of growth of rice is attributed to the presence of high levels of availability of these ions.

MANY permanently waterlogged mangrove soils of Sierra Leone contain sulphides. If these soils are empoldered to exclude salt water they dry at the surface during the dry season and the sulphides are oxidized. One effect of this oxidation is that the pH value of the soil falls and rice is unable to grow. The phenomenon is of considerable practical importance and a knowledge of the range of pH toleration of the rice plant and of the actual cause of death of rice plants in soils of low pH would be of value in the development of methods of soil amelioration.

As reported below, the fall of pH on drying a small sample of a sulphidic mangrove soil is very rapid, and by drying such samples for different periods of time it is possible to prepare a series of soil samples which covers a range of pH values from approximately 7 to 2·5 sufficiently rapidly for the series to be used in a single investigation of rice growth. Such a series is of particular value in the investigation of the dependence of rice growth upon soil pH, for if the initial sampling errors in the collection of the soil samples to be dried may be thus obviated, the only differences of properties between different soils of the series are those due to their different pH values.

It is unlikely that the concentration of the hydrogen ion itself is responsible for the death of plants in soils of moderately low pH. Lundegårdh [1] has calculated that the hydrogen-ion concentration of the root surface of a young wheat plant is equivalent to a pH of 3, and Arnon and his co-workers [2] showed that many crops grew satisfactorily in solutions with pH values ranging from 4 to 8, provided that precautions were taken to eliminate harmful secondary effects; see also

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Russell [3]. Wallace [4] remarks that the amounts of aluminium, manganese, and iron dissolved from soils are largely dependent upon soil reaction and that in strongly acid soils available manganese and aluminium in particular may assume concentrations which are toxic to plants.

In the experiments described in this paper rice seedings were transplanted into a series of soils of different pH values and their growth observed. Samples of the soils were taken and the amounts of the three ions which are likely to be toxic were determined in them. The object of the experiments was to determine the soil pH at which adverse effects on the growth of rice became noticeable and whether the level of availability of any of the ions in the soils increased rapidly in the neighbourhood of this pH value. Such an increase may be taken as an indication that the ion in question is likely to be toxic to rice at the level of availability found in the soil.

Experimental Methods

Growth experiments. The soil chosen for the experiment was surface soil from the bottom of a subsidiary drain in Rokupr Experimental Farm. The soil is a recent sediment and is heavy and structureless; it was chosen because it was known to be sulphidic and to become acid on drying. The rice used in the experiment was of the variety 'Lead', which is one of the commonest rices of short duration grown in the tidal swamps of north-west Sierra Leone.

A series of soils of different pH values was obtained by drying samples of soil in 12-in. papier-mâché plant pots. The plant pots were all filled with the chosen soil on the same day and the periods for which the soils in the different pots were allowed to dry were chosen by using data obtained in a separate preliminary investigation of the rate of change of pH of the soil on drying. The soils were mixed thoroughly every second day during drying to ensure that drying was even throughout the pots.

The rice seedlings were grown, prior to transplanting, in papier-mâché pots filled with sandy non-sulphidic soil taken from the surface of a slightly elevated area of Rokupr Experimental Farm. Batches of 100 seeds were sown at such intervals as to make the rice seedlings of the same age at the time of transplanting into the samples of soil which had been dried for different periods. Immediately after the seed was sown the plant pot was watered with 500 ml. complete nutrient solution [5]. The plant pots were kept in a plant cage and watered with tap water as seemed necessary, and with further lots of 250 ml. complete nutrient solution twice weekly. There was severe insect attack on the later batches of seedlings and it was necessary to spray them with a dilute suspension of a commercial preparation of benzene hexachloride. Percentage germination of seeds decreased from about 80 per cent. with early batches to about 30 per cent. with later ones.

The rice seedlings were transplanted into the dried soils at an age of 28 days. Immediately before the operation the soils were watered and an attempt was made to puddle them. However, there was a

tendency for water-stable aggregates to be formed when the soils dried and it was not possible to puddle the drier soils satisfactorily. As a result these soils were comparatively free-draining and it was difficult to maintain the water-table at the surface of the soil. Whenever possible ten seedlings were transplanted into each 12-in. plant pot, but in some of the later batches there were insufficient seedlings, due to poor germination and insect attack, and it was necessary to reduce this number. At the same time as a batch of seedlings was transplanted into a dried soil, a second batch, matched with it as closely as possible, was planted into a fresh sample of the same soil as control. At the time of transplanting, soil samples were taken from each pot for laboratory examination.

The pots containing the seedlings were examined each morning and evening during the experiment and tap water added as necessary so that water stood on the surface of the soil. In general, drainage was better with dried than with fresh soil samples, so that it was necessary to add more water to the test pots than to their corresponding controls and, to this extent, test and control batches of seedlings did not receive identical treatment. In spite of frequent watering, however, the soils were not waterlogged at all times and intermittent drying during the period when the rice seedlings were growing may account for changes in soil pH observed during the experiment. On the other hand, such changes of pH may be inevitable, for it was shown that the pH of a partially dried soil continued to fall on storage, even in an atmosphere of nitrogen.

The seedlings were grown in the pots until they were 80 days old, the growth of seedlings in test and control soils being compared at frequent intervals. Although the plants had not reached maturity after this period, it was clear that they were crowded in the pots and they were therefore harvested. Above- and below-ground parts of the plants ('shoots' and 'roots') were collected separately. Soil particles were removed from the roots as carefully as possible in a stream of water, but it is doubtful whether all the soil was removed and some of the finer roots were certainly lost in the attempt to do so. Soil samples were taken for laboratory examination at the time of harvesting. The total shoots and roots of each batch of plants were dried at 105° C. overnight and weighed, the weights of material so obtained being taken as measures of growth.

Laboratory soil examinations. The pH was determined in a suspension of approximately 1 part of soil to 2 of distilled water using a Cambridge Portable pH Meter. The determinations were made as soon as possible after the collection of the soil samples, which were stored meanwhile in air-tight glass bottles.

The moisture contents of the soil samples were determined by drying the samples at 105° C. for 6 hours.

The soil samples were extracted with an approximately normal solution of ammonium acetate, the pH of which was adjusted to within 0·2 units of that of the soil to be extracted by the addition of acetic acid or ammonia solution. Before analysis the soil extracts were evaporated

to dryness and ignited at 600° C. for 20 minutes, after which the residues were dissolved in dilute hydrochloric acid.

The solutions were analysed for *calcium* and *magnesium* by titration with the disodium salt of ethylene-diamine-tetra-acetic acid; calcium alone was determined by titration in alkaline solution using murexide as indicator, and calcium and magnesium together by titration in solution buffered to pH 10 with a mixture of ammonium hydroxide and ammonium chloride, using Eriochrome Black T as indicator [6]. High concentrations of ions which interfere with these methods of determination were present in the extracts of the more acid soils and such interfering ions were removed by complexing them with sodium diethyldithio-carbamate and extraction of the complexes with amyl alcohol as described by Cheng, Melsted, and Bray [7]. *Iron* was determined colorimetrically by complexing with sulphosalicylic acid in ammoniacal solution using the method described by Koulter-Andersson [8]. *Aluminium* was determined colorimetrically by complexing with ammonium aurine tricarboxylate [9]. *Manganese* was determined colorimetrically after oxidation to permanganate with potassium periodate: see Snell and Snell [10]. *Phosphate* was determined colorimetrically as phosphomolybdenum blue using the modification of the Denigés method described by Yuen and Pollard [11].

Experimental Results

Preliminary experiment. A sample of soil was dried in a beaker in the laboratory to determine the approximate rate of fall of pH on drying, which must be known before the intervals at which the batches of rice seedlings should be planted can be chosen. The results of the experiment are given in Table 1.

TABLE 1. *Rate of Change of Soil pH with Drying*

No. of days drying	*pH*	*Moisture, % wet soil*
0	6·84	58·1
1	6·80	57·6
2	6·42	53·1
4	5·91	54·5
5	5·77	53·8
7	4·98	51·1
9	4·14	48·5
12	3·10	45·0
15	2·90	40·1
19	2·59	34·6
23	2·48	27·1
32	2·54	14·3

Growth experiments. Of the ninety-three control seedlings transplanted only one died. At pHs above 5·0 growth of the test seedlings was comparable with that of the controls, tillering being only slightly less with Batch D at pH 5·09 than with its control. Below this pH,

however, growth of the seedlings was restricted, the visible effects being a reduction in the number of tillers and a tendency for the older leaves to die back from the tips: there was no unusual colour development in the leaves. Below a pH of about 4·0 (there is some uncertainty in this figure due to the high final pH of Batch H, some of the seedlings of which died soon after transplanting) some of the seedlings of a batch died while the remainder were very stunted. Below a pH of about 3·0 all the seedlings of a batch died soon after transplanting.

The change of pH of the soils while the rice seedlings were growing in them makes it necessary to use a mean pH value when the results of the experiments are interpreted. The mean chosen was the arithmetic mean of the pH values themselves. Since the pH scale is a logarithmic one, this mean is not the same as the true pH value derived from the arithmetic mean of the hydrogen-ion concentrations which the original pH values represent, but gives undue weight to the higher of the two pH values. However, the differences between the arithmetic means of the initial and final pH values, and the pH values which represent the arithmetic means of the initial and final hydrogen-ion concentrations are usually small. The mean used was chosen because the value of the pH of the soil at the actual time of transplanting, when the seedlings must re-establish their root systems, was considered to be the more important.

The results of the growth experiments are given in Table 2, showing the weight in grammes per surviving plant for each batch of test seedlings and the pH values of the soil on which each batch was grown, together with notes on the growth of the seedlings. Similar data for the control seedlings are not included in the table; all the control batches of seedlings grew well, averaging over 2 gm. total dry weight per plant, and the average pH of the soils in which the control seedlings were grown was well over 6. The weights of shoot and of root per surviving seedling for both test and control batches are plotted against the corresponding mean soil pH values in Figs. 1 and 2 respectively. (Plottings of the ratios of the total weights of the shoots and roots of the test seedlings to those of the corresponding control seedlings are similar to the curves shown in Figs. 1 and 2, but their interpretation is complicated because of variations in the pH values of the control soils.) The rapid decrease in growth below pH 5 is clearly seen; variation in yield of grain would have been still more marked, for it is unlikely that some of the plants which made poor growth would have set seed.

Laboratory examination of soil samples. The calcium and magnesium contents of the soil extracts showed so great a scatter as to mask any possible variation of level with soil pH. There was also considerable scatter of the values for manganese content, but this did not completely mask a tendency for the manganese level to rise as the soil pH fell; the increase was, however, relatively small.

Extractable iron and aluminium contents are plotted against soil pH in Fig. 3, in which the scale for iron is one-tenth of that for aluminium. The main differences between the two ions are that the proportional increase of the iron content was greater than that of the aluminium

TABLE 2. *Growth of Rice Seedlings in Soils Dried for Varying Times, and pH Values of the Soils, Excluding Controls*

Rice	*No. of days of drying*	*No. of seedlings*		*Weight per surviving seedling (gm.)*			*pH*			*Notes on growth*
		Planted	*Survived*	*Shoots*	*Roots*	*Total*	*Initial*	*Final*	*Mean*	
Batch B	3	10	10	1·495	0·603	2·115	5·50	5·32	5·41	Soil more fibrous than typical. Restricted tillering, die-back of leaf tips, poor root development, particularly of fine roots.
Batch C	5	10	7	0·357	0·094	0·451	4·44	3·18	3·81	
Batch D	7	10	10	1·496	0·502	1·998	5·57	4·62	5·09	Slightly less tillering than control. No die-back. Extensive roots.
Batch E	9	10	10	0·823	0·183	1·065	5·52	3·62	4·57	Noticeably poorer tillering than Batch D or Control E. Fine root development restricted.
Batch F	12	10	10	0·603	0·057	0·670	5·11	3·62	4·37	Two survivors feeble. Tillering and base development poor. Root development poor. Plants shorter than control.
Batch G	15	10	9	0·359	0·093	0·452	4·16	3·55	3·86	Poor growth as regards both height and tillering.
Batch H	18	10	5	0·424	0·135	0·559	3·93	5·39	4·66	Poor growth, as Batch G. Poor root development, maybe some thickening.
Batch J	22	10	0	0	0	0	3·20	2·55	2·88	Five seedlings died in 1 week and the remainder in 3 weeks.
Batch K	26	7	0	0	0	0	2·65	2·42	2·54	All seedlings died within 1 week.
Batch L	30	6	0	0	0	0	2·56	2·41	2·49	All seedlings probably dead in 2 or 3 days, certainly in 1 week.

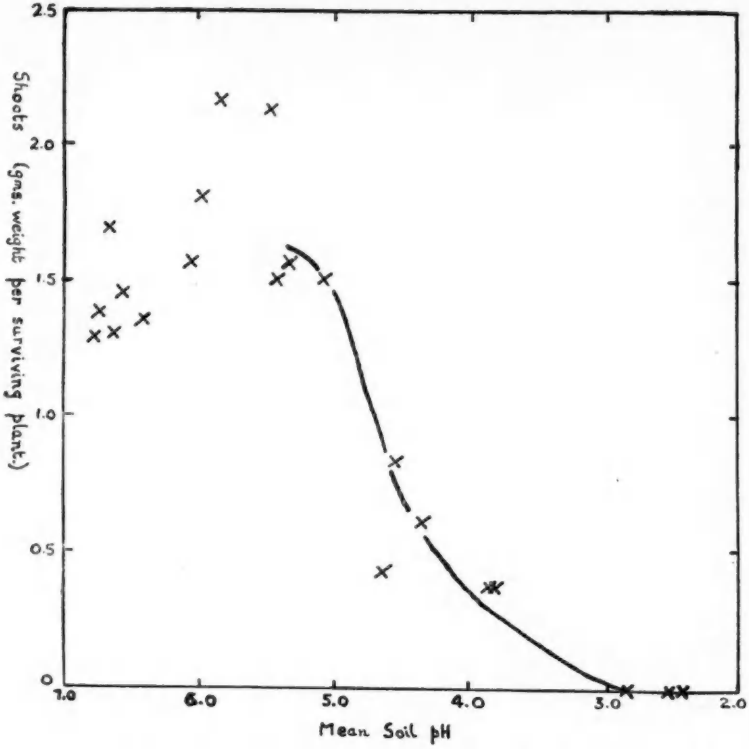

FIG. 1. Weight of shoots per surviving plant (including controls) plotted against mean soil pH.

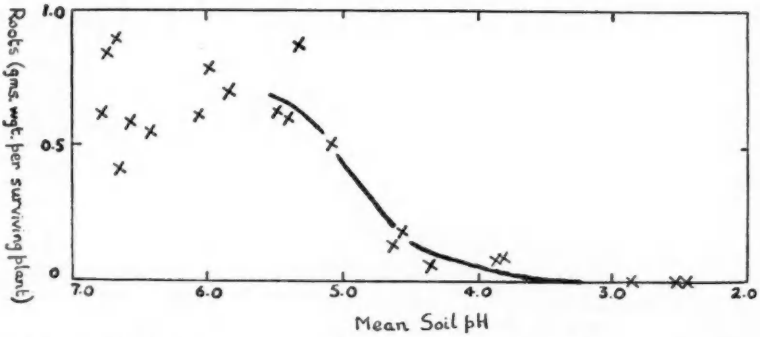

FIG. 2. Weight of roots per surviving plant (including controls) plotted against mean soil pH.

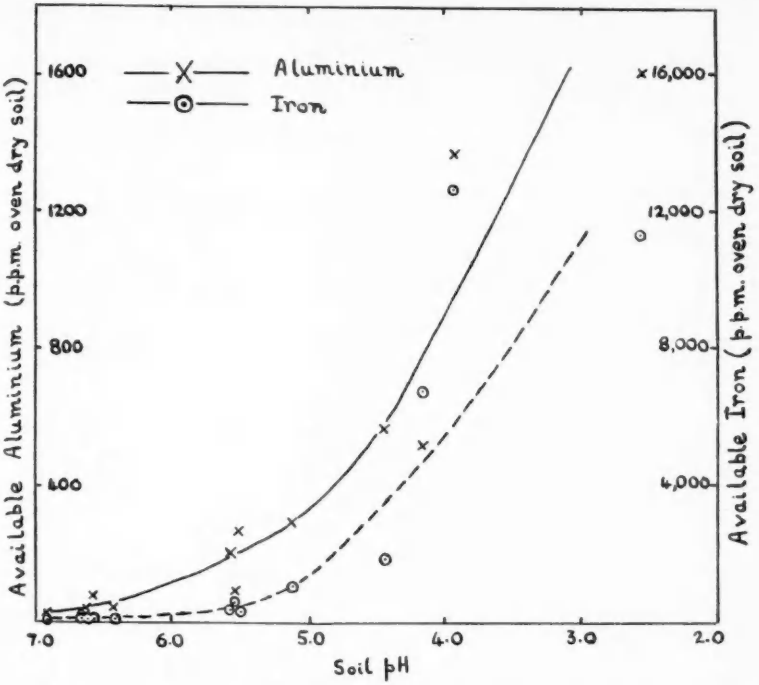

FIG. 3. The relation of extractable (total) iron and aluminium contents and soil pH.

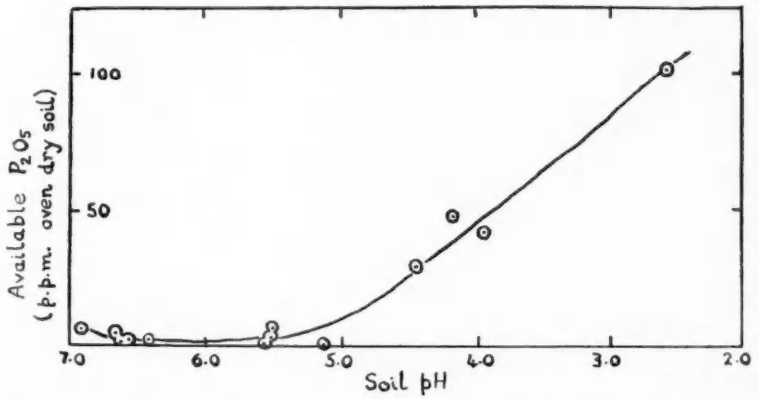

FIG. 4. The relation of extractable phosphate content and soil pH.

content, and that the increase of the aluminium content began at a slightly higher soil pH than that for the iron content. If the iron extracted is in the ferric form, the latter observation might be explained by the fact that aluminium hydroxide is a slightly stronger base than ferric hydroxide.

The amounts of phosphate extracted are plotted against soil pH in Fig. 4. A comparison of this figure with Fig. 3 shows that the increase of extractable phosphate as the soil became more acid began at about the same soil pH as the increase of extractable iron. This suggests that immobilized phosphate in the soils is associated with iron. However, the increase of extractable iron was proportionately much greater than that of extractable phosphate, so that all the iron released in acid soils cannot be associated with phosphate.

Discussion

The lower limiting soil pH value for the satisfactory growth of rice indicated in the present investigation is in good agreement with the value quoted by Richer [12], who gives 5·5 to 6·5 as the soil pH range for the optimum growth of rice, but also states that the plant will grow fairly well in soils at least 0·5 pH units above and below these limits. The limiting value found here is, however, in poorer agreement with the statement of Grist [13] that the pH value of good paddy soils usually varies from 4 to 6.

A comparison of the soil pH value at which the growth of rice began to be restricted and the values at which the amounts of available iron and aluminium began to increase gives a clear indication that one or both of these ions was responsible for the restriction of rice growth. Using the data here reported, however, it is not possible to determine whether only one of the ions is responsible for the effect. If the toxic ion is iron we should expect a level of 1,000 p.p.m. (oven-dry soil) to be harmful to rice and one above 10,000 p.p.m. to be toxic, while, if aluminium is the toxic ion, the corresponding levels would be 250 and 1,500 p.p.m. However, these levels may be dependent upon the amounts of other available ions in the soil and upon the organic matter content.

It is unlikely that the small increase in the amount of available manganese is responsible for the restriction of rice growth at low soil pHs. Since the scatter which is involved in the collection of soil samples has little effect upon the relationship observed between rice growth and soil pH value, it would be expected that this relationship is dominated by some factor which is itself relatively unaffected by sampling scatter. Clearly the amount of available manganese in the soil does not satisfy this requirement.

The reduction of the tillering of rice in the pH range 5 to 4 will seriously affect the yield of the crop and is of considerable practical importance. An increase in the pH value of a soil is most commonly achieved by the addition of lime. However, since it is unlikely that the concentration of the hydrogen-ion itself is responsible for the death of plants in soils of moderately low pH, adjustment of soil pH will only

be effective in improving plant growth if there is a simultaneous reduction of the levels of availability of those ions which are toxic in the acid soil. Unpublished results obtained recently at this station suggest that an increase of soil pH leads to a reduction of the level of available aluminium irrespective of whether the soil is leached or not, but that there is a rapid marked decrease in the level of available iron only if the soil is heavily leached.

Another important effect of the liming of soils is the influence on the trace-element availability in the soils, either by ion antagonism or as a result of the change of pH value. This effect is unlikely to be serious in the mangrove soils of Sierra Leone. The soils are alluvial and, unless permanently saline or empoldered and allowed to dry, are very fertile. Piggott [14] has investigated the fertilizer requirements of rice grown on such soils and concludes that phosphate supply is probably the only limiting factor. The adequate supply of trace elements may often be due to the fact that the soils are subject to saline tidal wash during a short period in the dry season.

If the soils of some tidal swamps in Sierra Leone are empoldered to exclude salt water and are allowed to dry during the dry season, areas of very acid soil may result [15]. Field experiments have been performed in which heavy dressings of lime were applied to such acid areas, but the 'lime requirements' of the soils were not determined. The heavy dressings resulted in large increases in yield. The experiments were performed in Wellington Polder in the Sierra Leone Colony. In the first experiment in 1948, a dressing of burnt and crushed oyster shells equivalent to 10 tons of CaO per acre produced a marked response in rice growth [16]. In another experiment in 1951, a dressing of 3 tons of lime per acre increased the yield of paddy from 80 to 1,680 lb. per acre [17]. However, most of the rice in Sierra Leone is grown as a subsistence crop by traditional methods and the economics of liming such acid soils are dominated by the absence of a local source of liming material. In spite of the relatively high market price of rice in the country, the dressings of lime used in the experiments have corresponded to an initial outlay of several times the value of a single rice crop and, even if there are marked residual effects of liming these soils, it is doubtful whether the practice would be attractive to the local farmers.

The importance of the present work is its indication that almost as great an increase in the yield of rice would be expected from the liming of a soil of pH 4 as of one of pH 2. The quantity of lime necessary may thus be much reduced, and this point, which does not seem to have been appreciated in earlier work, makes it possible that some acid mangrove soils might be limed economically. Work is at present in progress at this station to determine the dressings of lime which are necessary to adjust the pH values of such soils to values suitable for the growth of rice and to investigate the influence of such dressings of lime on the levels of available iron and aluminium in the soils.

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CONTROL OF POWDERY MILDEW DISEASES IN THE SUDAN, WITH SPECIAL REFERENCE TO BROAD BEANS

M. A. NOUR

(*Faculty of Agriculture, University College of Khartoum,*[1] *Sudan*)

Summary

A review of the literature and of the occurrence of powdery mildews in the Sudan is given.

The suitability of some commercial fungicide preparations of lime-sulphur, water-dispersible sulphur, sulphur dust, thiram, cuprous oxide, for control of powdery mildews, was tested upon several crops, especially broad beans, in the Sudan. Phytotoxic effect was observed at the higher concentrations of some of the sulphur fungicides, and may also have caused some reduction in yield of broad beans when lime-sulphur was used at medium concentration.

Control of *Leveillula taurica*, *Sphaerotheca fuliginea*, and *Erysiphe cichoracearum* was obtained with all the fungicides. *L. taurica* and *E. umbelliferarum* on broad beans were controlled by the lime-sulphur and sulphur-dust preparations; although the latter appeared more effective, it was irritant to the eyes. Early sowing combined with spraying with the lime-sulphur preparation at low concentration resulted in considerably increased yields of broad beans at two experimental centres.

The applicability of the results for the control of powdery mildew on broad beans in the Sudan is discussed.

SEVERAL species of the Erysiphaceae occur in the Sudan as parasites on various crop plants, weeds, and other vegetation. Boughey [1] and Tarr [2] have recorded their occurrence, sometimes with severe damage to crops when conditions were favourable to the parasite. With the exception of *Erysiphe graminis* DC., which is occasionally reported to attack wheat and barley in the northern-most region of the Sudan (Dougola-Halfa area), the other species are distributed throughout northern Sudan, upon a wide host-range for each species.

They are prevalent during the warm winter months of December to April when most of the susceptible crops are grown. It is likely that this period is more favourable to their spread than the hot dry summer or hot humid Kharif (rainy) season in central parts of northern Sudan. Were crops available at other times of the year, conditions might possibly be equally favourable for the spread and development of these fungi.

Boughey [3] found that there was a high negative correlation between mean annual rainfall and the incidence of the mildews. They are, however, by no means confined to the drier provinces of the Sudan nor to the drier seasons of the year. *Erysiphe cichoracearum* DC. severely attacks *Hibiscus esculentus* L. in Khartoum Province in May and June, when the mean daily maximum temperature is about 42° C., the mean day temperature 33° C. and the mean daily relative humidity at 0800 hrs. 25 per cent. *Sphaerotheca fuliginea* (Schlecht) Poll. on the same host south of the Gezira occurs abundantly during the humid warm months of July to October, where mean daily minimum and maximum temperatures range between 18 and 32° C., and relative humidity at

[1] Now University of Khartoum.

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0800 hrs. between 55 and 75 per cent. *Leveillula taurica* (Lev.) Arn., the species with the widest geographical distribution and greatest host-range in the Sudan occurs in many parts of northern and central Sudan throughout the whole year upon crop plants (e.g. *Hibiscus esculentus*), and on several weeds (e.g. *Euphorbia heterophylla* L. and *Abutilon* spp.). It occurs in Egypt on *Cynara scolymus* L. and other crops during the winter, where the temperature for November to February varies between about 20 and 14° C. and the relative humidity is from 80 to 86 per cent. *E. cichoracearum* on cucurbits also occurs extensively in Egypt during the autumn and winter, causing severe damage. The range of tolerance, of *L. taurica* in particular, and of *E. cichoracearum* and *S. fuliginea* to a lesser extent, is therefore extremely wide. *E. polygoni* DC., also known to occur in northern and central Sudan on several winter crops [1], has been less studied but is believed to occur only under warm dry winter conditions, and the damage caused has not been assessed as great. Uppal and Desai [4] in their investigation of *E. polygoni* on *Cuminum cyminum* L. in Bombay note that the disease spreads and develops with extreme rapidity in the moist warm weather (26–35° C.) of January and February.

Apart from a few pests and probably a virus disease, powdery mildews are the main agents causing damage to broad beans in the northern Sudan. The primary source of infection by *E. umbelliferarum* de Bary and *E. polygoni* is not known. With *L. taurica*, cleistothecia have not been observed on this host and only rarely on any of the wide range of species infected by this parasite. Previous reports suggested that *L. taurica* like other mildews is strictly specialized [5]. Viability tests carried out at Shambat showed that the conidia were extremely short-lived (unpublished work) so the possibility of infection by long-distance wind-borne conidia from adjacent countries is slight. Furthermore, with the prevailing northerly winds during winter, the infection, if wind-borne, must necessarily come from Egypt; although this crop is extensively grown in upper and lower Egypt during the winter months, *L. taurica* is reported to occur on it only in isolated pockets, such as the Oases.

During the course of this investigation, however, conidia of *L. taurica* from *Euphorbia heterophylla* L. (a widespread susceptible weed in northern Sudan) and several varieties of American cotton (*Gossypium hirstum* L.) and Egyptian cotton (*G. barbadense* L.) were found to be capable of infecting leaves of broad beans. Inoculations in the reverse direction were also successful [6]. Since the infection can thus be transferred easily from one host species to another, it appears that *L. taurica* can behave as a generalized parasite. Moreover, it is reasonable to assume that, at least under Shambat conditions, the disease which persists throughout the year in its active conidial form on *E. heterophylla*, infects broad beans when that crop is available.

Control of Powdery Mildew

It is well established that control of powdery mildew diseases can be achieved by application of sulphur and also, though not so effectively, by copper fungicides. Much work on the control of these parasites and

the effect of outside environment on the efficiency of the fungicides was done by Yarwood [7] in America. He found that some powdery mildews can be controlled even by periodical water sprayings [8]. Stoner [9] in Florida reported that 30 lb./acre of sulphur applied as a dust at the right time controlled *L. taurica* on *Hibiscus cannabinus* L. Of the newer fungicides, dinitrocaprylphenyl crotonate (Karathane) is stated to control *E. cichoracearum* on cantaloupe melons [10], and *E. polygoni* on beans [11].

Most of the work on powdery-mildew control in the Middle East has been done in Egypt [12], Israel [13, 14], and North Africa [15]. In the Sudan, the decrease in yield (e.g. of broad beans attacked by *E. umbelliferarum* and *L. taurica*) though not properly assessed, is believed to be as high as 50 per cent. at times. However, little attention has been given to these parasites and their control in the Sudan in the past, possibly because most of the crops susceptible to them are of secondary importance in the economy of the Sudan as a whole. Being mainly pulse and vegetable crops they are nevertheless most important, and the need for their protection is gradually being realized.

Crops attacked by Powdery Mildew in the Sudan

The more important crops attacked, and their powdery-mildew parasites, in the Sudan, are listed below.

TABLE 1. *The Chief Crops Susceptible to Powdery Mildew in the Sudan*

Crops	*Parasites*
Broad bean; *Faba bona* Medic (= *Vicia faba* L.)	*Erisyphe umbelliferarum*
	Leveillula taurica
	E. polygoni
Carrot; *Daucus carota* L.	*L. taurica*
	E. polygoni (= *E. umbelliferarum*?)
Sesame; *Sesamum orientale* L.*	*L. taurica*
Safflower; *Carthamus tinctorius* L.*	*L. taurica*
Chick pea; *Cicer arietinum* L.	*L. taurica*
Egyptian cotton; *Gossypium barbadense* L.†	*L. taurica*
American cotton; *G. hirsutum* L.†	*L. taurica*
Okra; *Hibiscus esculentus* L.	*L. taurica*
	E. cichoracearum
	Sphaerotheca fuliginea
Vegetable marrow; *Cucurbita pepo* L.	*S. fuliginea*
Pumpkin, &c.; *C. maxima* Duchse.	*S. fuliginea*
Cucumber; *Cucumis sativus* L.	*S. fuliginea*
Melon; *C. melo* L.	*S. fuliginea*

* Grown under rain-fed cultivation. The remainder are grown with artificial or basin irrigation.

† New record.

Broad bean. This is a winter crop sown in November and harvested in March in the Northern Province. Its southern limit is Khartoum Province and there the temperature is suboptimal for its growth owing

to the shorter and warmer winter period. This crop is of great importance in many Middle-Eastern countries where the dry beans are boiled and eaten with oil or butter as a breakfast diet. Owing to its relative cheapness this dish has become highly popular especially among the poorer masses in the Sudan and in urban districts.

L. taurica appears on this crop in northern Sudan towards the end of December, some 6 weeks after the crop is sown. The disease spreads slowly, usually infecting the upper leaf surfaces and appearing particularly on the older leaves. By the end of January *E. umbelliferarum* appears and spreads rapidly on old as well as young leaves, causing severe reddening of the leaves and their premature death. Formerly it was thought that *L. taurica*, or to a lesser degree *E. polygoni*, were the only powdery mildews causing the damage, but it has been established that the heavy attack in February and early March is primarily caused by the *E. umbelliferarum*.

Okra and the cucurbits. These crops are grown in practically all parts of the Sudan when water is available. Pods of okra form a national diet and are cooked fresh or dried for future use by all classes of the community. As vegetable crops the cucurbits, okra, and carrots, are intensively cultivated near large towns.

Tests of fungicides for the control of mildew were made especially on these crops because they form an important food for both urban and rural communities in the Sudan, and because they appear to suffer most from mildews. They are easy to grow at Shambat and in the readily accessible Shendi-Berber area.

Preliminary Investigation (1953–4)

A preliminary investigation was made at Shambat (Faculty of Agriculture farm) during the season 1953–4.

The test included the following twelve treatments (in the form of the commercial preparations named in parentheses):

A. *Lime-sulphur* (Sulfinette), at dilutions (in water) of 1:20; 1:40; and 1:80, with a wetting agent (Agral LN).
B. *Water-dispersible sulphur* (Spersul), at 2, 4, and 10 rotls per feddan.[1]
C. *Thiram*, i.e. *tetramethylthiuram disulphide* (Tulisan), at 2, 4, and 10 rotls per feddan.
D. *Sulphur dust* (Special Spreading Sulphur (S.S.S.)), at 20, 40, and 80 rotls per feddan.
E. *Control:* no treatment.

The layout comprised 1 feddan divided into forty plots each subdivided into three equal strips which were sown respectively with okra, broad beans, and vegetable marrow, arranged at random, on 15 November 1953.

The above twelve fungicide treatments were applied, at random, in

[1] 1 rotl = 0·99 lb.; 1 feddan = 1·038 acres; 1 rotl per feddan (r.p.f.) = 1 lb. per acre, approx.

three replications, to thirty-six plots, leaving four untreated plots as controls. The volume of spray solution or suspension applied in each treatment was at the rate of 80 gallons per feddan; these, and the dust (Treatment D), were applied three times, at 2-weekly intervals. Spraying and dusting were started in the last week of December, when the disease had appeared on both okra and marrow but not on broad beans, which did not become mildewed until the first week of January 1955.

TABLE 2. *Preliminary Investigation, 1953–4. Phytotoxicity and Mildew Control by certain Fungicides on Three Crops*

Crop / *Treatments*	*Okra*		*Broad beans*		*Vegetable marrow*	
	*Phyto-toxicity**	*Control of disease†*	*Phyto-toxicity**	*Control of disease†*	*Phyto-toxicity**	*Control of disease†*
Lime-sulphur (A)						
1:20 dilution	+	++	++	++	+	++
1:40 ,,	−	++	+	++	+	++
1:80 ,,	−	++	−	++	−	++
Water-dispersible sulphur (B)						
2 r.p.f.	−	−	−	−	−	−
4 ,,	−	+	−	+	−	+
10 ,,	−	++	++	++	++	++
Thiram (C)						
2 r.p.f.	−	−	−	−	−	−
4 ,,	−	−	−	−	−	+
10 ,,	−	+	++	++	+	+
Sulphur dust (D)						
20 r.p.f.	−	++	−	++	−	++
40 ,,	−	++	−	++	−	++
80 ,,	−	++	−	++	−	++

* *Phytotoxicity*: ++ = Death of whole or part of leaf where the fungicide was deposited.
+ = Damage not amounting to death of mature leaf. (Sometimes death occurring on young leaves of broad bean.)
− = No damage.

† *Control of disease*: ++ = Complete control of disease.
+ = Disease appearing sometimes on healthy treated leaves.
− = No control of disease.

The results (Table 2) indicated that all the fungicides, under the conditions of the experiment, were effective in controlling powdery mildew on the three crops used. Phytotoxic effects were well marked only upon broad bean leaves, and less marked on marrow leaves; in both cases at the higher fungicide concentrations.

Experiments on Broad Beans in 1954–5

From the results obtained in 1953–4, the lime-sulphur spray (Sulfinette, with Agral LN as wetting agent) and sulphur-dust (Special Spreading Sulphur, S.S.S.) treatments were used in these experiments.

The nine randomized treatments were:

A. *Lime-sulphur*,* at 1:80 dilution, in 3 applications at 2-weekly intervals.
B. *Lime-sulphur*,* at 1:80 dilution, in 2 applications at 3-weekly intervals.
C. *Lime-sulphur*,* at 1:40 dilution, in 3 applications at 2-weekly intervals.
D. *Lime-sulphur*,* at 1:40 dilution, in 2 applications at 3-weekly intervals.
E. *Sulphur dust*, at a rate of 22½ r.p.f., in 3 applications at 2-weekly intervals.
F. *Sulphur dust*, at a rate of 22½ r.p.f., in 2 applications at 3-weekly intervals.
G. *Sulphur dust*, at a rate of 45 r.p.f., in 3 applications at 2-weekly intervals.
H. *Sulphur dust*, at a rate of 45 r.p.f., in 2 applications at 3-weekly intervals.
I. *Control*, no treatment.

* The volume of lime-sulphur spray in each application was at the rate of 80 gallons per feddan.

Two 5-feddan units were selected, one at Aliab and the other at Shendi, both about 150–200 miles north of Khartoum, each being artificially irrigated from the Nile. The soil at Aliab is heavy, sodium-alkaline, marginal in fertility, and with great tendency to waterlogging, and therefore less suited to a broad-bean crop; yields at Aliab average 2–3 ardabs[1] per feddan. Shendi on the other hand has a fertile light friable soil and normally produces good yields of broad beans by Sudan standards (3–5 ardabs per feddan). The broad-bean crop is invariably attacked by *L. taurica* and *E. umbelliferarum* in both localities.

Each of the five 1-feddan blocks at each centre was divided into nine N.–S. strip plots, one for each of the above treatments (to minimize the drift effect of the north wind in winter), giving five replications in each experiment.

Local broad-bean seed was sown at the same rate at each centre, in ridges, on 15 November 1954. Germination was high with insignificant differences between plots and therefore this factor was not considered in the final analysis.

The disease appeared first on the lower leaves at each centre in the first week of January, more than 2 weeks after flowering. By 15 January it was lightly spread on the lower leaves at isolated points; it became most severe in February not only because of the favourable climatic conditions but also because the host is then mature, when its resistance appears to be lowest. (Some plots sown with broad beans on or near the original unit at each centre on 27 January 1956 were only mildly attacked by the end of February).

The first application of fungicides was given on all treatments on 15 January at both centres. The second and third applications in the

[1] 1 ardab = 5 bushels, approx.

TABLE 3. *Grading of Leaves from Different Treatments for Coverage by Powdery Mildew at Different Dates in Experiments at Shendi in 1954–5 (see p. 126) and at Fadlab in 1955–6 (see p. 129)*

Treatments	*A*					*B*					*C*					*D*					*Control*				
Grades	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
Shendi:																									
10.1.55 .	80	16	4	0	0	90	5	3	1	1	95	2	1	2	0	86	3	1	8	2	88	4	5	1	2
10.2.55 .	72	20	6	2	0	82	9	4	1	4	90	4	6	0	0	90	5	2	3	0	34	12	17	19	18
1.3.55 .	70	14	2	4	10	74	12	6	4	4	90	2	6	0	0	80	4	10	0	6	4	11	20	10	55
Fadlab:																									
14.1.56 .	93	4	2	1	0	90	2	3	3	2	94	1	3	1	1	91	4	4	0	1	88	6	4	1	1
10.2.56 .	90	2	3	3	2	86	3	1	6	4	75	10	4	5	6	86	3	5	3	3	53	17	11	2	17
1.3.56 .	84	8	4	3	1	88	2	4	2	4	68	8	5	4	15	74	6	0	2	18	6	8	20	8	58

Treatments	*E*					*F*					*G*					*H*					*Control*				
Grades	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*	*0*	*1*	*2*	*3*	*4*
Shendi:																									
10.1.55 .	92	3	1	4	0	88	2	4	4	2	92	4	1	1	2	90	3	2	3	2	88	4	5	1	2
10.2.55 .	90	1	4	1	4	86	5	8	1	0	90	0	6	1	3	91	4	3	0	2	34	12	17	19	18
1.3.55 .	85	3	2	6	4	80	10	8	0	2	85	7	2	4	2	82	9	5	2	2	4	11	20	10	55
Fadlab:																									
14.1.56 .	94	2	2	2	0	96	2	1	1	0	92	2	2	3	1	—	—	—	—	—	88	6	4	1	1
10.2.56 .	62	4	17	6	11	40	19	10	5	26	90	1	4	3	2	—	—	—	—	—	53	17	11	2	17
1.3.56 .	10	12	28	8	42	2	5	10	10	73	82	9	1	4	4	—	—	—	—	—	6	8	20	8	58

Grade value: 0 = no disease.
" " 1 = 1/10 of leaf area covered.
" " 2 = 1/5 " "
" " 3 = 1/2 " " Some reddening of leaves
" " 4 = 3/4 to whole " Much reddening of leaves

2-weekly treatments (A, C, E, and G) were made on 30 January and 13 February, and the second application in the 3-weekly treatments (B, D, F, and H) on 5 February.

At both centres the treated plots were relatively free from the disease. At Shendi a random sample of 1,000 leaves was taken on each plot on each of three dates, and the leaves in each sample were graded according to the degree of coverage by the mildew. The total number of leaves in each grade for each treatment was expressed as a percentage of the number of leaves graded for that treatment. Most of the mildew on the treated plots occurred on the lower leaves, which were protected from the spray. The results are given in the upper part of Table 3 which shows that the disease was effectively controlled by the fungicides at both concentrations and dates. The same method of leaf-grading was used at Aliab and the final result was closely similar to the findings at Shendi.

The mean yields of beans with the different treatments at Aliab are given in Table 4.

TABLE 4. *Experiment at Aliab in 1954–5. Mean Yields of Broad Beans in Rotls per Plot of $\frac{1}{9}$ feddan with Different Rates and Frequencies of Application of Fungicides* (*see pp. 123–4*)

Fungicide	*Lime-sulphur*			*Sulphur dust*			*Control*
Rate of application	*Frequency of application*			*Frequency of application*			
	2-weekly	*3-weekly*	*Mean*	*2-weekly*	*3-weekly*	*Mean*	
Light . .	80·0 (A)	85·0 (B)	82·5	85·8 (E)	72·4 (F)	79·1	54·6 (I)
Heavy . .	75·2 (C)	92·0 (D)	83·6	95·0 (G)	83·4 (H)	89·2	
Mean . .	77·6	88·5		90·4	77·9		

S.E. of individual treatment means (A–I) ±4·0. S.E. of means for light and heavy applications ±2·8.

The mean yield from the control treatment was significantly less ($P = 0{\cdot}01$) than that from any of the other treatments at Aliab. The means for each of the three factors considered separately, namely: form of fungicide, frequency, and rate of application, showed no significant differences. However the interaction of forms of fungicide × frequency was highly significant. With lime-sulphur, the yield with 3-weekly application was significantly better than that with 2-weekly, but for sulphur dust the reverse was true.

The mean yields of beans with the different treatments at Shendi are given in Table 5.

At Shendi the yields with sulphur dust were generally higher than with lime-sulphur or than on the control plots, but, in contrast, with Aliab, the general level of yields for the treated plots was about twice, and of the controls nearly thrice as high, and the differences were not significant except perhaps for sulphur dust at the higher rate, with an indication that, as at Aliab, the 2-weekly applications of lime-sulphur were superior to the 3-weekly.

TABLE 5. *Experiment at Shendi in 1954–5. Mean Yields of Broad Beans in Rotls per Plot of $\frac{1}{6}$ feddan with Different Rates and Frequencies of Application of Fungicides* (*see pp. 123–24*)

Fungicide	*Lime-sulphur*			*Sulphur dust*			*Control*
Rate of application	*Frequency of application*			*Frequency of application*			
	2-weekly	*3-weekly*	*Mean*	*2-weekly*	*3-weekly*	*Mean*	
Light .	158·0 (A)	164·4 (B)	161·2	163·0 (E)	169·2 (F)	166·1	160·6 (I)
Heavy .	147·8 (C)	167·2 (D)	157·5	186·0 (G)	177·0 (H)	181·5	
Mean	152·9	165·8		174·5	173·1		

S.E. of individual treatment means (A–I) ±8·6. S.E. of means for light and heavy applications ±6·1.

The following observations are relevant in this connexion. The wind-drift effect produced a definite zone of inhibition of the disease on the control plots, particularly on the south, east, and west sides, the ridges in the centre and on the northern sides of the control plots, however, were heavily mildewed. This effect was greater at Shendi than at Aliab. At the latter centre the plants were of medium height and so more precise spraying and dusting was feasible. At Shendi the growth was tall and the application of the fungicides therefore involved a wider spread of spray, with more resulting drift. Moreover, the height of the crop at Shendi, and its interlocking branching, resulted in a substantial loss through breakage in the last application, whereas there was no breakage on the controls. The Shendi soil was far more fertile than that at Aliab, which was doubtless responsible for the much stronger growth and the high yield of the control plots, which were thus able to reach the same level of yield as the treated plots without any fungicide and despite the abundance of the disease on them.

In treatment C with 1:40 lime-sulphur every 2 weeks the yield was lower at both Shendi and Aliab, indicating a possibility of phytotoxic effect, although no effect was visible on the plants.

Experiments on Broad Beans in 1955–6

During the 1955–6 season further experiments were carried out using lime-sulphur (Sulphinette) and cuprous oxide (Perenox). Lower concentrations of lime-sulphur were applied, since it had been found, as reported above, that even the spray drift of this fungicide sufficed to cause a marked reduction of mildew attack, and that at its higher concentrations the lime-sulphur seemed to have a toxic effect on the plant. Although the sulphur-dust preparation proved as potent as, if not more so, than lime-sulphur, in 1954–5, its main drawback was that it induced severe eye irritation which might last for several days, though apparently without any harmful after-effects. It was therefore not used in the 1955–6 experiments.

The randomized treatments were:

A. *Lime-sulphur* at 1:80 dilution, in one application at Shambat and in two applications at Fadlab.
B. *Lime-sulphur* at 1:100 dilution, in one application at Shambat and in two applications at Fadlab.
C. *Lime-sulphur* at 1:120 dilution, in one application at Shambat and in two applications at Fadlab.
D. *Lime-sulphur* at 1:120+DDT 1 lb. per feddan, in one application at Shambat and in two applications at Fadlab.
E. *Cuprous oxide* at 3 lb. per feddan, in one application at Shambat and in two applications at Fadlab.
F. *Seed Treatment* at 1:450 weight of T.M.T. Gamma BHC YF 3607.
G. (Early-sown) *Lime-sulphur* at 1:120 dilution, in two applications at Shambat and in three at Fadlab.
H. *Control*, no treatment.

A wetting agent (Agral LN) was used with lime-sulphur and cuprous oxide. The dual or treble applications (Treatments A, B, C, D, E at Fadlab and G at Fadlab and Shambat), were at 3-weekly intervals.

DDT was incorporated together with lime-sulphur in treatment D because it was observed that a pest of wide distribution in northern Sudan, *Helicothrips* sp., occurred abundantly on the broad-bean crop in the early season during December and January, sometimes causing severe local damage. The application of a presowing seed-treatment of Gamma BHC+organo mercuric dust (TMT) was included as treatment F to study the effect on germination and on subsequent reaction to the disease.

The experiments were carried out in two localities, at Shambat near Khartoum and at Fadlab on the west bank of the Nile opposite Atbara town. No critical soil analysis was made at either site, but the textures of the soils and their pH values were similar. Both were fertile light clay soils with a pH of about 8·5. At each locality five 1-feddan blocks were each divided into eight strip plots running parallel to the winter wind direction, giving five randomized blocks at each site. The seed used was of the same stock at both localities. Sowing was by hand on ridges, with equal spacing between the ridges and between the holes, on 5 and 8 November 1955 for treatment G and on 24 and 28 November for the rest of the treatments at Shambat and Fadlab respectively.

The germination at both sites was over 98 per cent. on all plots and resowing was done at only a few points that suffered from waterlogging in the first watering.

At Fadlab the three applications in treatment G were made on the 11 and 30 January, and 19 February; and the two applications in treatments A, B, C, D, E on 30 January and 19 February 1956. At Shambat the two applications in treatment G were made on 17 January and 8 February; the single applications in treatments A, B, C, D, E on 8 February. Each spray application was at the rate of 80 gallons per feddan.

In treatment D the DDT-lime-sulphur combination had no visible

harmful effect on the crop. Thrips attack at both sites was generally mild but there was a marked absence of this pest with treatment D. No adverse response to any of the other treatments was observed.

The disease first appeared on 28 December at Fadlab and 5 January at Shambat on the early-sown plots. Its spread was slow during the following four weeks, when it was established mildly on all the plots at both sites but confined to the lower leaves.

The disease became very severe and spread rapidly after the first week of February on the control and to a lesser degree on the cuprous-oxide-treated plots at both sites. The drift effect on the controls was less obvious than in the previous year's experiments. However, only the centre four ridges (equivalent to 144 sq. metres) out of the ten in each plot were sampled for yield. The degree of severity of the disease on the leaves from the centre four rows, measured by the same grading method as that used in the 1954–5 experiments, is given in the lower part of Table 3 for the experiment at Fadlab; similar measurements were not made at Shambat but the general appearance of the plants suggested an essentially similar picture.

The plots were harvested on 10–20 March at both centres. The yields per plot (144 sq. metres), and the mean weight of 100 seeds selected at random, were used in the statistical analysis. The results for both centres are given in Table 6.

TABLE 6. *Experiments at Shambat and Fadlab in 1955–6. Mean Yields of Broad Beans in Rotls per 144 sq. metres, with Different Fungicidal Treatments* (*see pp. 127–8*)

Treatment	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H Control*	*S.E.*
Yields at Shambat	27·3	41·3	34·9	42·0	31·3	43·7	55·0	32·2	±4·4
Yields at Fadlab	42·3	48·2	39·6	40·2	42·0	37·5	51·4	35·7	±2·8

At Fadlab the yields from treatments B and G were significantly better than those from treatment F, or from the control, at the $P = 0{\cdot}01$ level, and than that from treatment C at the $P = 0{\cdot}05$ level. There was no significant difference between the yields from the other treatments and that from the control. The seed-treatment, though without effect on yield at Fadlab, had a significant effect at Shambat; although all the other treatments gave higher yields than the control, only that from treatment G differed significantly from the control at the $P = 0{\cdot}01$ level.

There was no significant difference between treatments at either centre in the 100-seed weight.

Discussion

Although the results from the two centres in 1955–6 cannot be pooled owing to the differences in date of application as well as the natural differences between the sites, when they are taken in conjunction with those of the 1954–5 experiments definite indications of the effect of

fungicides have been obtained. Lime-sulphur at dilutions of 1:80 or less seems to have had on the whole little effect in increasing yield, perhaps because its phytotoxic effect at such dilutions outweighed its fungicidal action. At its medium dilution of 1:100, however, in two applications, the yield was increased at Fadlab by more than 30 per cent. over the control, and by more than 13 per cent. over that with the 1:80 dilution. It is obvious that the 1:100 dilution was optimal for the crop sown at the normal time at Fadlab. Lime-sulphur at the higher dilution of 1:120, without DDT, has clearly proved to be ineffective in increasing yield of the crop sown at the normal date, and the better yields obtained when it was used with DDT may have been due more to control of thrips than to mildew control. However the combination of this same concentration with early sowing produced highly significant increases in yield. This treatment gave outstandingly the best result at both centres in 1955–6, but it is not possible to judge to what extent this depended upon early sowing or upon the use of lime-sulphur, and whether the latter would have proved even better at the 1:100 dilution on the early-sown crop. Further work is required, in which these two factors should be tested separately. There are indications that early-sown crops are less affected by attacks of the disease. From the earlier experiment, however, as well as from the effect of 1:100 lime-sulphur in treatment B at Fadlab (1955–6), this fungicide has been clearly shown to have brought about a substantial increase in yield.

The problem of the practical application of this finding in the Northern Province of the Sudan, where the disease is most severe, remains to be solved. The fact that the area under broad beans is limited will offer a difficulty, since local cultivators will be discouraged from attempting mildew-control by the initial cost of equipment, however simple it may be. An added difficulty is the physical damage liable to be caused to the crop in the second and third spraying if the soil is fertile and growth dense. It appears, however, that lime-sulphur can most profitably be used to protect broad beans from mildew in the marginal heavy clays such as occur at Aliab.

Cuprous oxide on the other hand proved to be inferior to lime-sulphur, judged not only from the relatively poor yield but also from its poor effectiveness in controlling the disease at the concentration used. This is seen clearly from the field observations on the extent of mildew on the leaves at Fadlab. Sulphur dust showed promise of giving even better control of the disease than that obtained with lime-sulphur, but since its irritant effect on the eyes would make it unpopular with growers, it was not considered worth while to include it in the later experiments.

As *Leveillula taurica* appeared on broad beans almost 2 months after sowing, it is highly unlikely that the primary infection could have come from seed-borne mycelium. It has been shown by Cherewick [16] that powdery mildews perennate in cold climates commonly in their cleistothecial state, and sometimes as dormant resistant mycelium on dead straw. Under tropical and subtropical conditions cleistothecia are seldom produced, and often lack differentiated ascospores when they are formed. Further study is required to explain how these specialized powdery

mildews (i.e. *E. umbelliferarum*, *E. polygoni*) pass through the 'dead' season under tropical conditions, when volunteer plants do not exist. With *L. taurica*, however, it has been established that the mildew continues on some weeds throughout the year in the conidial state and that it is capable of infecting broad beans. This serves to emphasize the importance of weed control in combating the disease.

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SEASONAL PRODUCTION OF BEEF AND VEAL IN NEW ZEALAND AND THE CONSEQUENT PATTERN OF EXPORTS

R. A. MACKNESS

(*School of Agriculture, University of Cambridge*)

Summary

This paper presents the problem of seasonality of beef and veal production in New Zealand and its effect on the pattern of exports. Exports of frozen beef have tended to become more seasonal and have arrived in the United Kingdom during the autumn when home-killed supplies of beef are available in large quantities. It would be preferable if future New Zealand beef exports to the United Kingdom might be modelled on the pattern of chilled exports obtaining before 1939.

THE purpose of this paper, which is the third in the series, is to present the problem of seasonality of beef and veal production in New Zealand and the effect seasonality has on the supply of beef and veal for the United Kingdom market. The first and second papers dealt with seasonal production in the United Kingdom [1] and in Australia [2].

Climatic conditions in New Zealand favour grass production and allow grazing nearly all the year. It is not surprising, therefore, that emphasis has been placed on livestock production, both for internal consumption and for export. Before 1939 lamb and dairy products were the main exports, but since 1939 beef and veal exports have been of increasing significance.

The long-term contracts first negotiated between New Zealand and the United Kingdom in 1939 provided the stability needed to induce producers to expand production of beef and veal. Further, the reclamation schemes undertaken by the New Zealand Government are providing about 50,000 acres of new farmland annually, thus making available more land suitable for livestock husbandry. In the event, between 1939 and 1955 dairy cattle increased from 2·6 millions to 3·1 millions, an increase of 20 per cent., whereas beef cattle increased from 2·0 millions to 2·8 millions, an increase of 40 per cent. More particularly beef cattle breeding stock increased by 45 per cent., and beef cattle may well increase substantially in numbers in the years ahead. Comparative figures for the sheep population show that total sheep have increased by 21 per cent. and breeding ewes by 33 per cent. As with beef cattle, sheep may be expected to continue to increase.

New Zealand production, consumption, total exports, and exports to the United Kingdom of beef and veal between 1930 and 1954 are shown in the Appendix. Production has expanded from 95,000 tons in the year ended March 1931 to 198,800 tons in the year ended September 1954. Between the calendar years 1930 and 1954, exports of carcass beef and veal increased from 20,950 tons to 52,300 tons and those destined for the

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United Kingdom rose from 17,000 to 41,000 tons. Although total New Zealand internal consumption increased by about 30,000 tons between 1930 and 1954, annual consumption a head fell slightly. Less beef and veal were consumed in 1954 than in 1938, and annual consumption a head in 1953 was only 107 pounds, compared with 127 pounds in 1938.

New Zealand Production

Beef and veal in New Zealand are produced primarily for home consumption, being derived as a by-product of dairy herds and from pure beef herds. Beef destined for export comes mainly from the beef breeds, since that produced from dairy herds would not be sufficiently competitive on the world market.

The incentives provided by the war-time world shortage of meat are reflected in the increase in New Zealand beef production since 1939, compared with the position between 1930 and 1939. The average annual production between 1930 and 1939 was 136,200 tons, whereas it was 180,000 tons between 1939 and 1945, and 183,000 tons between 1945 and 1953. Thus post-war annual production has increased by nearly 35 per cent. compared with the pre-war level. Further increases in output will depend on the competitive position of beef enterprises. The state reclamation schemes will provide the land for increased pastoral production. Whether this land is used for beef cattle will depend on the level of profits New Zealand farmers expect from beef, sheep, or dairy products and the competition these products meet on the world market.

Unfortunately, data published by the New Zealand Census and Statistics Department are not sufficiently detailed to allow an analysis of the seasonal variation of beef and veal production before 1948. It is possible, however, to infer seasonality of production from available data of New Zealand exports, which will be considered in the next section.

TABLE 1. *Indices of the Average Monthly Slaughtering of Calves and Cattle in New Zealand and Killings for Export, 1948–53*

Month	*Total calves*	*Total cattle*	*Killings for export*
January	14·2	72·3	47·0
February	11·7	102·3	89·6
March	15·9	134·0	145·1
April	19·0	164·9	209·0
May	19·9	206·7	272·4
June	26·5	143·1	176·7
July	234·1	93·8	89·5
August	435·6	61·1	59·8
September	232·0	51·4	37·6
October	116·6	55·2	23·9
November	55·4	57·0	25·6
December	19·1	58·2	23·8
Average	100·0	100·0	100·0
Standard deviation	128·3	49·1	79·1

An analysis of the pattern of slaughtering of calves and cattle between 1948 and 1953 shows the extremely seasonal character of calf slaughtering, and, to a lesser extent, of cattle slaughtering. The figures in Table 1 show the indices of average monthly slaughterings, together with the standard deviation. Calf slaughtering is concentrated between July and October inclusive, when about 85 per cent. of the calves are slaughtered; August is the peak month when 35 per cent. are killed.

This highly seasonal pattern reflects the incidence of spring calving. The cattle-slaughter pattern is much less seasonal than the calf-slaughter pattern, being concentrated between March and June inclusive, when 54 per cent. of the cattle are killed, with May as the peak month. Of the cattle specifically destined for export two-thirds are slaughtered between March and June, and the pattern of export killings is more seasonal than that of total slaughtering.

Data on a quarterly basis are available in sufficient detail for the years 1949–53 to allow an analysis of the seasonal variation of production and consumption, and this is shown in Table 2.

The effect of the high slaughter rate of cattle between April and June is clearly seen in the production data.

TABLE 2. *Indices of the Average Quarterly Production and Consumption of Carcass Beef and Veal in New Zealand, 1949–53*

Period	*Production*	*Consumption*
1st quarter (Jan.–Mar.) . . .	86·4	96·6
2nd quarter (April–June) . .	146·7	105·6
3rd quarter (July–Sept.) . .	103·8	102·2
4th quarter (Oct.–Dec.) . .	63·1	95·6
Average	100·0	100·0
Standard deviation . . .	30·6	4·1
Annual average: '000 tons . .	182·2	100·3

On the other hand the highly seasonal calf slaughtering between July and September hardly affects the seasonal pattern of the total beef and veal production, because veal only provides about 11 per cent. of the total.

The pattern of consumption of beef and veal in New Zealand is very regular during the year, varying little from quarter to quarter. It is apparent, therefore, that the seasonal pattern of production must affect the pattern of exports.

New Zealand Exports

The data in the Appendix include total New Zealand exports of carcass beef and veal for the calendar years from 1930 to 1953 and the quantity exported to the United Kingdom. As production increased faster than internal consumption the exportable surplus increased. Consumption which was estimated at 127 pounds a head between 1937 and 1939, fell to 96 pounds a head in 1946 and was 107 pounds a head in 1953. New Zealand consumed slightly less beef annually in the years 1950 to 1953 than in the period 1935 to 1938.

A feature of the New Zealand beef export trade before 1939 was the very large proportion sent to the United Kingdom. During the war the United Kingdom continued to receive nearly all the exportable surplus and this was maintained until 1952. In that year the New Zealand Government announced that it would attempt to find other markets, although it would continue to supply the United Kingdom so long as the price received was competitive. In the event, in 1952 only 48 per cent. of New Zealand's exports of beef went to the United Kingdom, a lower percentage than in any year since 1930. However, in 1953 and 1954 the proportion sent to the United Kingdom increased to about 80 per cent. of total exports.

The patterns of New Zealand frozen beef and veal exports for periods between 1930 and 1935 are set out in Table 3.

TABLE 3. *Indices of the Average Monthly Exports of Frozen Carcass Beef and Veal from New Zealand, 1930–53*

Month	*1930–5*	*1936–9*	*1940–5*	*1946–9*	*1950–3*
January	68·9	68·3	117·2	118·9	21·8
February	71·4	71·6	110·2	47·3	43·1
March	111·5	99·1	61·3	27·1	54·9
April	88·8	63·9	35·2	54·1	62·5
May	145·1	116·6	119·1	107·2	108·7
June	126·2	113·3	91·3	173·8	179·4
July	117·2	136·1	79·7	107·8	186·2
August	89·2	144·0	65·3	95·6	217·7
September	104·2	126·1	104·6	159·9	140·9
October	81·3	116·9	128·8	113·8	117·6
November	121·4	85·6	190·0	98·2	45·2
December	74·8	58·5	97·3	96·3	22·0
Average	100·0	100·0	100·0	100·0	100·0
Standard deviation	23·5	28·4	37·7	40·7	65·4
Average annual quantity exported: '000 tons	34·8	36·2	37·0	63·9	50·7

The increasing size of the standard deviation of the monthly indices from the average shows that New Zealand's frozen beef exports have become more seasonally varied. Between 1930 and 1935 the peak period of beef exports was between May and July, when 32 per cent. of the annual frozen beef shipments left New Zealand; November shipments were about 20 per cent. above monthly average and contributed 10 per cent. of the annual quantity dispatched. From 1937 to 1939 frozen beef exports between May and October accounted for 63 per cent. of the annual quantity, August being the peak month, and 34 per cent. of the annual total was shipped between July and September. During the war years beef exports became more seasonally varied and the peak month was November, although the index for January, February, May, and October was well above 100. About 16 per cent. of the total annual exports between 1940 and 1945 were shipped in November. From 1946 to 1949 exports during February and March declined, whereas peak

shipments were in June and September, giving a greater seasonal variation; the November peak experienced during 1940 to 1945 disappeared. The pattern of exports between 1950 and 1953 was very similar to that of the years 1936 to 1939, although it was more seasonally varied; between June and August 40 per cent. of the annual exports were shipped, with August as the peak month.

This concentration of exports of frozen beef in the months June to August is unfortunate, because they would normally arrive on the United Kingdom market at the same time as the above-average marketing of grass-fed British fat cattle in the autumn. An analysis of seasonal variation of New Zealand chilled beef exports for the years 1936 to 1939 shows that February and March were the months of greatest shipments, followed by above-average monthly shipments in May, June, and July. Such a pattern of exports was advantageous because beef arriving by such shipments could not clash with the United Kingdom home-produced glut in the autumn. In fact chilled beef exports in the five months August to December in the years 1936 to 1939 were less than one-third of the annual chilled shipments.

Chilled beef exported from New Zealand became of increasing importance from 1936 to 1939, when it was stopped by the war. Shipments increased from 12,000 tons in 1936 to 17,000 tons in 1938, and 15,500 tons were shipped in the first eight months of 1939.

It is to be hoped that the future pattern of New Zealand chilled and frozen exports to the United Kingdom will be similar to that of chilled exports before 1939. In that way New Zealand would provide beef for the United Kingdom market when home-killed beef supplies are seasonally below the average for the year.

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APPENDIX

Production, Consumption, and Exports of New Zealand Beef and Veal, 1930–54, in thousands of tons

Year	*Production*	*Consumption*	*Year*	*Total exports*	*Exports to U.K.*
Apr.–Mar.					
1930–1	95·0	73·5	1930	20·95	17·80
1931–2	94·5	73·0	1931	23·60	22·30
1932–3	114·0	73·5	1932	26·75	26·50
1933–4	138·5	91·5	1933	46·45	45·95
1934–5	141·5	97·5	1934	44·90	44·70
1935–6	163·0	112·0	1935	46·30	43·90
1936–7	147·0	106·0	1936	42·55	42·00
1937–8	169·5	114·0	1937	50·10	49·40
Oct.–Sept.					
1938–9	163·0	N.A.	1938	51·70	51·10
1939–40	186·0	N.A.	1939	61·15	N.A.
1940–1	174·0	N.A.	1940	74·80	N.A.
1941–2	181·0	N.A.	1941	39·55	N.A.
1942–3	193·0	N.A.	1942	45·90	N.A.
1943–4	166·0	N.A.	1943	25·40	N.A.
1944–5	180·0	N.A.	1944	7·05	N.A.
1945–6	176·0	N.A.	1945	29·45	N.A.
1946–7	188·1	79·4	1946	61·40	60·10
1947–8	185·9	81·4	1947	67·40	67·15
1948–9	177·6	93·7	1948	67·90	66·90
1949–50	185·4	96·9	1949	59·00	57·60
1950–1	177·2	104·4	1950	59·00	56·30
1951–2	192·1	102·3	1951	42·90	38·80
1952–3	182·0	97·6	1952	56·50	27·40
1953–4	198·8	100·9	1953	44·40	36·90
			1954	52·30	41·00

N.A. = Not available.

THE NODULATION OF ANNUAL LEGUMINOUS CROPS IN MALAYA

G. B. MASEFIELD

(*Department of Agriculture, University of Oxford*)

Summary

A field reconnaissance was carried out in Malaya on the nodulation of annual leguminous crops, by digging up samples and examining their root systems. The degree of nodulation of cowpeas, groundnuts, French beans, soya beans, yam beans, peas, and green gram on ordinary soils was very low compared to legumes in the temperate zone, and low compared to the same crops in some other tropical countries. Much higher weights and numbers of nodules were attained where these crops were growing on soils with a high water-table (usually adjacent to paddy lands). Compared with the lowlands of Malaya, no greater degree of nodulation was attained by crops grown in the Cameron Highlands, at an altitude of about 4,700 ft. with a relatively cool climate. The rather rare crop *Psophocarpus tetragonolobus* (winged or four-angled bean) was found to nodulate more heavily than any other legume examined, confirming a previous observation made in Nigeria. When grown on a soil with high water-table, the exceptionally high figure of 21 gm. of nodules per plant was recorded, equivalent to over 6 cwt. of nodules per acre. In a field experiment, the weight of nodules on cowpeas was tripled by mulching, and also significantly increased by watering and decreased by extra cultivations, the weight of the plants also responding in the same way. The implications of these findings for agricultural practice are discussed.

In continuation of a previous survey of the nodulation of annual leguminous crops in the tropics [1], the observations made in Nigeria and the Sudan have been extensively supplemented by further records collected in Singapore and the Federation of Malaya between June and September 1956.

Experimental Methods

All the crops, with rare exceptions (referred to later), were sampled in the flowering stage. This stage is the most suitable time for examination, as nodulation is then at its peak, and the number and weight of nodules remain for a time at more or less constant levels since the few early nodules which are already decaying are replaced by a few late ones which are still growing.

Each sample normally consisted of twenty plants (averaging about one day's work for examination), except for groundnuts where nodules are normally very numerous and initially only ten plants per sample were examined. Later when it was found that groundnuts in Malaya often bore few nodules, up to twenty plants were examined in some samples. Occasionally with other crops twenty plants were not available, but never were less than ten taken except in two plots of *Psophocarpus tetragonolobus* where sampling was perforce restricted to six and eight respectively by lack of more plants or the great amount of time needed to examine heavily nodulated ones.

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Some samples came from plots specially planted for this investigation at agricultural experiment stations, at Kuala Lumpur and elsewhere. As few of the legumes in question are commonly grown in Malaya, other samples had to be taken where the crops could be located, so that adequate comparisons could be made in each region. Such samples came from Chinese and Malay small holdings, private gardens, a prison farm, &c.

In the tables which follow, village place-names have been omitted and the samples are grouped by regions. The 'North-West' region includes the States of Kedah and Perlis, 'North-East' the States of Kelantan and Trengganu. Selangor is a State in the West centre of the Malay peninsula; Cameron Highlands is a hill district in the State of Pahang with a general altitude of about 4,700 ft.

The plants in the sample were carefully lifted with a garden fork or Assam fork, the root system washed, and excess of water removed between cloths. In counting nodules, one confluent cluster was recorded as one nodule, and nodules too small to be detachable by forceps were not counted. Fuller details of the procedure have been given in an earlier paper [1]. Where possible, the whole plant was removed and its fresh weight recorded; but most of these legumes in Malaya are climbing forms, and in many cases of very vigorous growth it was impossible to separate individual plants, so that the weight of the whole plant could not be recorded.

Experimental Records

Comparison of Species

Vigna unguiculata[1] (*locally called 'long bean'*). This species, known elsewhere as cowpea, is the commonest annual legume grown in Malaya, the only variety being the climbing form, which is supported on sticks. A larger number of samples were obtained for this than for any other crop.

The outstanding features of Table 1 are the generally low weights and numbers of nodules per plant. The figures compare very unfavourably not only with annual legumes in the temperate zone, but with the same crop grown in Nigeria. In almost all the samples with a mean nodule weight of less than 0·10 gm., no nodules at all were found on some of the plants (sometimes amounting to more than half), and the remainder bore such rare nodules that these crops might be regarded for all practical purposes as devoid of nodules. There were, however, a few striking exceptions. Of the four samples which exceeded half a gramme of nodules per plant, it is to be noted that three came from soils with a high water-table and the fourth from the Kuala Lumpur agricultural station. The significance of these facts will be discussed later.

Phaseolus vulgaris (*French bean*). This crop was rarely found except in the Cameron Highlands. With one exception, only the climbing form supported on sticks was encountered. From Table 2 it is evident that the degree of nodulation was low indeed; on two samples nodules were

[1] Sometimes called *V. sinensis*.

absent. The only exception was from a site with a high water-table, and the second highest figure was from Kuala Lumpur agricultural station.

TABLE 1. *Nodulation of* Vigna unguiculata

Region	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean plant wt. (gm.)*	*Remarks*
Singapore .	1	0·02	1·5	105·3	
	2	0·35	24·7	..	
	3	0·25	15·8	63·3	
	4	0·004	2·3	50·0	
	5	0·29	22·2	..	
	6	0·06	11·2	87·4	
Selangor .	7	0·86	27·5	188·2	Kuala Lumpur agric. station
	8	0·001	0·05	82·1	
	9	0·35	27·5	161·9	
	10	0·08	3·6	..	
North-West .	11	0·06	3·7	75·5	
	12	3·69	60·0	..	Water-table at 7 in.
	13	0·07	14·3	219·4	
	14	0·03	2·9	..	Water-table at 9 in.
	15	0·02	1·9	..	
	16	0·69	24·9	95·0	Water-table at 15 in.
North-East .	17	0·26	12·3	63·3	
	18	0·12	26·8	85·2	
	19	0·93	57·5	109·5	Water-table at 6 in.

TABLE 2. *Nodulation of* Phaseolus vulgaris

Region	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean plant wt. (gm.)*	*Remarks*
Singapore .	20	..	none	..	
Selangor .	21	0·31	31·8	62·2	Kuala Lumpur agric. station
Cameron Highlands.	22	..	none	7·1	
	23	0·01	5·0	169·3	
	24	0·08	18·7	41·2	Dwarf form
	25	0·02	1·1	93·4	
North-West .	26	0·93	113·1	..	Water-table at 1 ft.

Arachis hypogaea (*Groundnuts*). Not many plots of this crop were met with; none was found in Singapore island. Only the erect or bunch variety is grown in Malaya.

Again the level of nodulation was very low (see Table 3) compared to figures for this crop from Nigeria and the Sudan. The sample from Kuala Lumpur agricultural station takes second place.

TABLE 3. *Nodulation of* Arachis hypogaea

Region	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean plant wt. (gm.)*	*Remarks*
Selangor .	27	0·40	287·0	120·1	Kuala Lumpur agric. station
	28	1·03	396·0	132·9	
North-West .	29	0·19	86·9	154·1	
	30	0·05	64·1	61·3	
	31	0·15	87·8	87·5	
North-East .	32	0·04	11·5	27·2	

Psophocarpus tetragonolobus (*locally called 'four-angled bean'*). This is, as in most countries, a very uncommon crop in Malaya, but in view of the weight of nodules found on the first batch of plants examined, every effort was made to find plots suitable for sampling, and five samples were obtained. By comparing the data of Table 4 with the other Tables 1–8, it will be seen that in every region where it was found, this crop exceeded all others in the weight of nodules produced. This high productivity is of particular interest since it confirms a similar finding for Nigeria [1], although since that figure derived from only a single site, no firm conclusions could be drawn at the time.

TABLE 4. *Nodulation of* Psophocarpus tetragonolobus

Region	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean plant wt. (gm.)*	*Remarks*
Singapore .	33	1·95	83·9	715·1	
Selangor .	34	3·46	66·0	98·1	Kuala Lumpur agric. station
	35	1·96	42·1	39·3	
Cameron Highlands.	36	0·20	1·9	99·7	
North-West .	37	21·65	441·2	..	Water-table at 7 in.

It could be advanced that comparisons of *Psophocarpus tetragonolobus* with other annual legumes are not strictly valid, since it is a facultative perennial which in Malaya is occasionally left in the ground for over a year, though none of these samples was so old. Sample No. 33 from Singapore was about 10 months old (which accounts for the high plant weight); on the other hand, the sample from Kuala Lumpur was under 2 months old and not yet in flower, yet it exceeded in nodule weight all other crops of the same age at this station. Sample No. 35 was approximately 2 months old and not in flower; No. 36 was 2·5 months and No. 37 5 months old. From such cursory examination of herbaceous perennial

legumes as the author was able to make, it appears likely that *P. tetragonolobus* also exceeds in nodulation most if not all of these species in Malaya.

Furthermore, the numbers and weights of nodules recorded for this species are more likely to be an underestimate of the true figures than for any other, since both lateral roots and individual nodules break off very easily and many of them had to be recovered by searching the soil after the plants had been dug up. Many of the nodules in this species were larger than in any other species examined in Malaya. The largest nodule found weighed 0·53 gm., and several others were over 0·40 gm.

The weight of nodules per plant in sample No. 37, the only one where this crop was found on a soil with high water-table, is higher than any figure for any legume in the previous surveys of tropical or temperate crops [1, 2], indeed the figure is greater than any that has been found in a search of the literature. This astonishing figure of 21 gm. of nodules per plant is equivalent, at the spacing at which the crop was being grown, to over 6 cwt. of nodules per acre.

A related species, *Psophocarpus palustris*, was being grown at Serdang agricultural station as a first introduction from Sumatra. No nodules at all could be found on these plants. Since Keuchenius [3] reports this species as nodulating freely in Indonesia, the most likely explanation seems to be that a compatible strain of Rhizobium was absent.

Glycine soya (*Soya bean*). The figures obtained for soya beans are given in Table 5. One sample was without nodules, the other figures are low with the exception of one abundantly nodulated crop on a soil with a high water-table.

TABLE 5. *Nodulation of* Glycine soya

Region	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean fresh plant wt. (gm.)*	*Remarks*
Selangor .	38	0·22	19·3	123·2	Kuala Lumpur agric. station
North-West .	39	..	none	11·5	
North-East .	40	0·03	0·9	15·4	
	41	3·29	256·3	146·7	Water-table at 5 in.

Pachyrhizus erosus (*Yam beans*). In addition to the results quoted in Table 6, two other samples of *P. erosus* were briefly examined, but after the first four plants of each had been found to be without nodules, further examination was discontinued. The highest of the very low figures again came from Kuala Lumpur agricultural station.

Pisum sativum (*Peas*). This crop was found only in the Cameron Highlands, and the figures obtained are given in Table 7. Nodules were few or absent.

Other crops. Records were obtained for a number of other crops, which were found at a suitable stage for sampling only in one or two places.

TABLE 6. *Nodulation of* Pachyrhizus erosus

Region	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean plant wt. (gm.)*	*Remarks*
Singapore .	42	0·007	0·6	146·6	
	43	0·004	0·3	46·8	
Selangor .	44	0·023	1·0	42·6	Kuala Lumpur agric. station
North-West .	45	..	none	167·0	

TABLE 7. *Nodulation of* Pisum sativum

Region	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean plant wt. (gm.)*
Cameron Highlands	46	..	none	7·1
	47	0·001	0·2	11·3
	48	0·03	16·1	7·3

All the figures for nodulation in Table 8 are low, save for one sample of *Phaseolus aureus* (green gram) from the Kuala Lumpur agricultural station. The sample of Canavalia was derived from plants not yet quite in flower, and it is probable that mature plants would have been more heavily nodulated, but an attempt to examine such plants from another site failed as the roots penetrated too deeply and broke off too easily for a fair estimate of nodulation to be obtained.

TABLE 8. *Nodulation of Various Minor Crops*

Crop	*Region*	*Sample no.*	*Mean fresh wt. of nodules per plant (gm.)*	*Mean no. of nodules per plant*	*Mean plant wt. (gm.)*	*Remarks*
Phaseolus aureus .	Selangor	49	0·42	29·8	24·3	Kuala Lumpur agric. station
	North-East	50	0·03	6·3	85·6	
Canavalia gladiata .	Singapore	51	0·01	7·2	32·9	
Dolichos lablab .	Singapore	52	0·15	6·6	..	
Voandzeia subterranea	Singapore	53	0·13	14·7	87·6	

Comparison of Regions

There is no consistent evidence, from the figures presented here, that nodulation is greater in any one region of Malaya than another. The North-West and North-East regions provide the highest figures, but that is because extensive rice areas in these regions happened to be flooded at the time of the author's visit, and it was in these areas that the

very wet soils were found which gave these high figures. One point is, however, of interest. It is apparent from Tables 2, 4, and 7 that nodulation in the Cameron Highlands was at no higher level than in the lowlands; in fact it was extremely low. This evidence provides no support for the argument by analogy that, because nodulation is generally higher in the temperate than tropical zones, it should also be so in a tropical highland area like the Cameron Highlands where the climate is in some degree 'temperate'.

Comparison of Soil Conditions

Crop samples were taken from soils of many types: sands, clays, silt, and peat; marine and riverine alluvium; and soils derived from granites and schists. Since no consistent differences in nodulation were found among any of these soil types, a description of the soil characteristics has been omitted.

The outstanding fact is that nodulation was exceptionally high on soils having a high water-table. This description covers soils of two groups. Most such sites were in plots within a few yards of paddy fields which were inundated at the time, so that adjacent land at the same level also had a very high water-table. Such sites, being very valuable for rice, are rarely used for other crops such as legumes, and this accounts for the small number of samples which could be found in this environment. Two samples (Cowpeas No. 14 and French beans No. 26) were on equally wet soils of a different kind, namely in swampy valley bottoms where Chinese market-gardeners were growing vegetables on raised beds among a network of drainage ditches. These sites are mainly used to raise non-leguminous leafy vegetables, especially Cruciferae, hence again the number of samples is small. In the first of these two samples, nodulation was not particularly high, the only instance where this was so on a wet soil.

Unfortunately all these wet soils were in remote areas where laboratory facilities were not available to determine moisture content or other soil characteristics. But no figures would adequately express the complete difference, from an agronomic point of view, between these wet soils and ordinary Malayan 'dry' soils. Not only was the water-table high, but the top soil above the water-table was also extremely wet. At one site at Alor Star, from which both cowpea sample No. 12 and Psophocarpus sample No. 37 (where the level of nodulation was exceptionally high) were obtained, the soil was a porridge-like slush; one could not walk on it for more than a step or two, even with bare feet, without one's foot suddenly penetrating several inches below the surface crust. In several of the samples from these wet soils, the crop was growing on raised beds with standing water between them.

In some of these samples, whole groups of nodules were found, on the lower part of the root system, which had decayed before their normal time. Evidently these nodules had been overtaken by a rising water-table at some period of their growth, and had rotted under immersion. This emphasizes the point that, while many nodules may be formed in

soils with a high water-table, they may not always have a very effective life.

That heavy nodulation on these wet soils is due to their wetness rather than to their physical or chemical characteristics, is supported by some figures obtained from the same soil type under 'dry' conditions. Thus cowpea sample No. 12 (wet) can be paired with cowpea No. 10 (dry) on the same formation of marine alluvium, and soya bean No. 41 (wet) with soya bean No. 40 (dry) on the same riverine alluvial clay. Both these soils manifested a very low level of nodulation when 'dry', but a very high one when the water-table was high.

One finding which could not be overlooked was the relatively high nodulation of six different legumes at Kuala Lumpur agricultural station, which had been planted there in small plots specially for this investigation. This point is brought out in the Tables. This soil—a brown silty loam—did not appear to have any unusual characteristic to account for such favourable results. Nor could these high figures be attributed to any differential factor of husbandry peculiar to an experimental station, since samples from several other stations of the Department did not give unusual results. These plots at Kuala Lumpur did, however, have one treatment lacking at all other sampling sites; they had been mulched with cut grass. In view of the findings on the effect of mulching, reported next in this section, it is considered that this may well provide sufficient explanation of the high nodulation.

The only field experiment which could be carried out during the author's stay in Malaya was designed to test the effect of certain soil treatments on nodulation. This was carried out on cowpeas planted on a sandy loam soil at Serdang experimental station in July and sampled in September. The layout was a Latin square with four treatments:

(*a*) Mulched with cut grass.
(*b*) Watered daily, except on days with a heavy rainfall.
(*c*) Hand-forked twice before sowing, in addition to normal cultivations. (This treatment was originally included to test a hypothesis that soil aeration is important for the nodulation of some legumes.)
(*d*) Control; none of above treatments.

The results obtained from this experiment are set out in Table 9.

TABLE 9. *Effect of Soil Treatments on Nodulation of Cowpeas, Serdang*

	Control	*Mulched*	*Watered*	*Forked*
Mean fresh wt. of nodules per plant (gm.)	0·35	1·05†	0·44†	0·07†
Mean no. of nodules per plant .	27·5	54·6	27·1	24·4
Mean plant wt. (gm.) . . .	161·9	279·0†	231·4†	105·3†

† Significantly different from control at P = 0·01.

It will be seen from this Table that mulching tripled the nodule weight, watering increased it to a lesser extent, and forking markedly decreased it. The fresh weight of the plants responded in the same manner, though the factor of increase was smaller (72 per cent. increase by

mulching). The differences in nodule numbers were smaller and in fact do not attain statistical significance, though they are all in the same direction as the others except for the watering treatment.

Under the local conditions of heavy rainfall and high temperatures, mulching may have acted in the same way as the watering treatment by increasing the content of soil moisture. The extra forkings produced a puffy soil with a raised level which lasted till the end of the experiment, and would be expected to increase evaporation and drainage, though other soil factors would also have been influenced. Unfortunately it was not possible to carry out periodic estimations of soil moisture content under the different treatments, as investigations in other parts of Malaya were being carried out while the crop was growing. If differences in soil moisture are the correct explanation of the experimental results, the small effect of the watering treatment may seem surprising, but this may be due to the small amount of water applied (one 2-gallon can per 15 ft. of row, with rows 3 ft. apart). Such an amount of water would penetrate only the top inch or two of the soil, and since, as shown later, nodules on cowpeas in Malaya are deep-seated, it may have had relatively little effect in the main zone of nodulation.

Evidence of Nitrogen Fixation

In almost all samples of all crops, most of the nodules when cut open showed a pink or red coloration. In one sample of cowpeas and in one of Psophocarpus only about half the nodules showed such colour, and in one sample of French beans, less than half. The degree of colour varied from a pale pink to the dark blood-red characteristic of mature ground-nut nodules. The red coloration was absent only in one sample of cowpeas and in the single samples of *Voandzeia subterranea* and *Dolichos lablab*. Apart from these, there is presumptive evidence of the presence of haemoglobin and hence of nitrogen fixation.

Some supporting evidence of active nitrogen fixation arose when a tin, filled with Psophocarpus nodules for subsequent preservation was, in the course of travel, left too long unopened. As a result, the nodules, which had been insufficiently dried, began to putrefy. When the tin was opened, a very strong ammoniacal smell was noted which may reasonably be taken as evidence of a high nitrogen content.

Depth of the Nodules

Many notes were taken on the morphology and other characteristics of the nodules, but since these confirmed in general that the symbionts, in each particular case, behaved in the same way in Malaya as elsewhere, details are omitted.

One point of some agronomic importance did, however, emerge. This concerned the depth in the soil at which the majority of the nodules were formed. Unfortunately the importance of this factor was not fully appreciated at first and the early records lack precision. In this connexion, although the distance of a nodule along a lateral root can be measured, its exact depth in the soil cannot be determined if the plant

is dug up in one operation, since the angle at which the root lay is uncertain. However, making the best allowance for these difficulties, it would seem that in the majority of samples of all crops the nodules were evenly distributed on the root system to a depth of about 9 in. The wet soils were exceptional; here nodulation in some cases stopped abruptly at or near the water-table a few inches below the surface. In extreme cases the even distribution of nodules continued as low as 14 in. in green gram, 16 in. in French beans, and 20 in. in cowpeas. Though no comparable figures for annual legumes have been noted in the samples taken in Britain, nodules in that case are certainly found at a lesser average depth in the soil, and normally the great majority are in the top 4 or 5 in. In the Malayan legumes there is no concentration of nodules thickly clustered on approximately the top 3 in. of the taproot and first laterals, which is so characteristic of annual leguminous crops in Britain.

This relatively great depth at which so many of the nodules are formed in Malaya indicates that any measures designed to increase nodulation must be applied so as to influence soil conditions at a considerable depth, and would explain why surface watering with small volumes of water may have little effect, as in the Serdang experiment (Table 9).

Correlation of Nodule Weight and Plant Weight

The agronomist is entitled to ask whether, if the weight of nodules on a crop is increased, its yield is also likely to be increased. The only figures obtained in this investigation which have any possible bearing on yield are the plant weights. Perusal of the tables will show that, as between different samples, there is little or no correlation between nodule weight and plant weight. But in this case the difference between the ecological environments of the plants which are being compared may vitiate the comparison.

The relation between plant and nodule weights within samples is of much more interest. Here also, however, not every sample can be used. In some cases, the plant weights were not obtained for reasons already explained. In other cases where nodulation was very low, no correlation between nodule weight and plant weight was ever found, nor was it arithmetically likely that it would be when many of the plants bore no nodules and on the remainder the extreme difference in nodule weights was often not more than one or two units in the last significant figure at the accuracy of weighing used. There remains a number of cases which could properly be tested to see whether there was a significant correlation between the weight of nodules on a plant and the weight of the plant. Among these there were nine samples with a statistically significant positive correlation and five with a suggestion of correlation; only three showed an obviously complete lack of correlation, and these included one sample of *Phaseolus vulgaris*, in which species it is known that nodulation is not always beneficial to yield, and one sample of Voandzeia where the nodules showed no haemoglobin, as well as one of soya beans.

The answer to this question is perhaps best sought in the field experi-

ment at Serdang (Table 9) where different treatments designed to affect nodulation were applied at the same site, and where mulching and watering which did increase nodule weights also produced an increase in plant weight, though (as is commonly the case in such experiments) not by so great a percentage.

Discussion

A field reconnaissance of this sort is designed to elucidate the nature of a problem in crop ecology, and to suggest lines for future research, rather than to provide conclusive or statistical proof of any particular hypothesis. Nevertheless, this investigation has produced interesting evidence on two points.

Although the environmental differences between the sites from which samples were taken are many, the figures obtained are in line with a hypothesis which has been advanced previously [1] on other evidence, that the water content of the soil is an important determining factor in the nodulation of tropical legumes. This suggestion, if confirmed, may have practical agricultural implications. If the nodulation, and possibly the yield, of such crops can be increased by raising the water content of the soil, irrigation is only one of the possible means of doing so. Most of the ordinary measures of soil conservation (e.g. strip-cropping, bunding, ridging) achieve the same effect, while the use of mulches, windbreaks, and shade may be valuable in some cases. The field experiment at Serdang (Table 9) shows how there may be a positive effect from simple agronomic practices such as mulching and watering, or a negative one from over-cultivation of the soil.

The second point is the clearly demonstrated capacity of the rather rare crop *Psophocarpus tetragonolobus* to form unusually large and numerous nodules. If a quantity of nodules equivalent to 6 cwt. per acre, as was found in one sample, could be produced at will there are obvious potential agricultural benefits. It is interesting in this connexion to note that analyses of the seeds of this species [4] show them to have a higher protein content than those of any leguminous grain crop except soya beans and lupins. Owing to its climbing habit the crop is not particularly promising as a green manure or cover crop, but it might prove possible to develop a non-climbing form, as has been done for many legumes, or it may be that the related wild species of the genus might provide useful material. But perhaps the chief interest of the information obtained is that this species may well prove to be valuable as experimental material in elucidating the factors that cause heavy nodulation.

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CALF MORTALITY, ABORTION, TWINNING, AND SEX RATIO IN EGYPTIAN BUFFALOES

A. A. ASKER[1] AND A. A. EL-ITRIBY

(*Animal and Poultry Breeding Department, Ministry of Agriculture, Cairo*)

Summary

The records kept by the Animal and Poultry Breeding Department, Ministry of Agriculture, at two stations were analysed to study the mortality rate of buffalo calves in Egypt. Sex ratio, twinning, and abortion were also investigated. 4,641 calves born during the last fifteen years were included in this report.

It has been found that the mortality rate of calves at the two stations was 33 per cent. from birth up to three years old. More than 80 per cent. of deaths occurred during the first six months. Male calves showed a slightly higher mortality rate than female ones. There were significant differences between different years in the mortality rates of calves. More than half of the deaths took place during winter months. The sex ratio in buffaloes was found to be 48 per cent. females to 52 per cent. males. Twinning and abortion in buffaloes were very low, being 0·2 and 1·1 per cent. respectively.

SUCCESS in raising healthy calves is an important item in dairy husbandry and herd improvement, since good management includes furnishing the herd with well bred young replacements. A high mortality rate of calves causes an actual monetary loss to the breeder besides the loss of some desirable genes.

For cattle, much work has been carried out on mortality of calves. In buffaloes, however, nothing is known about this subject. This investigation was therefore undertaken in an attempt to study the effect of age of the calf, sex, year, and month of calving on mortality rate of buffalo calves. Such information will throw some light on the method of rearing calves, and the steps that may be taken to reduce these losses. The sex ratio, abortion, and twinning in buffaloes were also studied as they are of interest for the breeder.

Material

The data used in this work were collected during the last fifteen years from two experiment stations of the Ministry of Agriculture. One of these stations (Sakha) is located in the northern part of the Delta, while the other (Sids) is about 100 miles south of Cairo. More than 4,500 calves were included in this investigation. Natural as well as artificial methods of suckling were used in raising the calves. All calves were left with their dams for 3 days after birth, to have the colostrum. In artificial suckling, the calves consumed about 700 lb. of milk before weaning, and milk was given twice daily. The amount of milk which the calf consumed per day was about 10 lb. at first, then it was increased gradually until it reached 14 lb. after few weeks. When the natural method was followed, the mother was allowed to suckle her young twice

[1] Present address: Faculty of Agriculture, University of Ein Shams, Sarai El-Kobra, Cairo, Egypt.

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daily for the first 45 days, then the calf suckled one-half of the udder for the following 2 months. In both systems, calves were allowed to nibble on green fodder and hay in addition to the milk. Weaning took place when calves were 4 months old. All calves were inoculated every year against haemorrhagic septicaemia during September and the tuberculin test was carried out every 6 months.

Results and Discussion

Mortality rate of calves. Table 1 shows the number and percentage of calves born alive and those which died up to three years old. It can be seen that calf losses came to 37·7 per cent. at Sakha, while it was only 19·7 per cent. at Sids, and the difference between the two stations was statistically significant. Such difference may be due to the fact that artificial suckling was used at Sakha on a larger scale. This system, unless the utensils used are clean and free from contamination, will be the source of many diseases which lead to greater losses. Moreover, it is known that the Egyptian fever (malaria) is an epidemic disease in the northern part of the Delta where Sakha is situated. The humidity in this part of the country is high and the mosquito is found in large numbers. In addition, better management and the warm climate at Sids also contributed to the low mortality rate of calves at this station.

TABLE 1. *Mortality of Calves in Egyptian Buffaloes*
(*Average for 1940–54*)

Station		Live calves born	Dead calves			Calves dead at different ages				
			Total	Males	Females	Birth to 6 mo.	6–12 mo.	12–18 mo.	18–24 mo.	24–36 mo.
Sids	no.	1,196	236	139	97	214	8	2	4	8
	%	..	19·7	11·5	8·1	90·7	3·4	0·8	1·7	3·4
Sakha	no.	3,396	1,281	662	619	1,027	157	36	15	46
	%	..	37·7	19·5	18·2	80·2	12·3	2·8	1·1	3·6
Total no.		4,592	1,517	801	716	1,241	165	38	19	54
Average	%	..	33·0	17·4	15·6	81·8	10·9	2·4	1·3	3·6

It should be noted also that no work has been carried out on artificial suckling of buffaloes, although in cattle this problem has been solved. Therefore, well-designed experiments should be carried out to study this system of suckling in buffaloes. Probably buffalo calves are overfed or the high percentage of butterfat in buffalo milk is detrimental.

The average mortality rate of calves for the two stations, 33 per cent., is higher than that found by the authors for native cattle, which was 15·9 per cent. (unpublished data), and also higher than that reported for dairy calves in temperate zones. Lassiter and Seath [1] and Davis [2] in the United States, and Braude and Walker [3] in England showed that mortality rate of calves in dairy breeds ranged between 10 and 20 per cent.

The difference between the present value for buffaloes and those reported by other workers abroad, is probably due to the fact that the

standard of feeding and management of calves abroad is higher than that practised in Egypt. Moreover, calves in Europe and the United States are kept in a healthy condition by regular inoculation and vaccination against many diseases.

The difference between mortality rate of calves in native cattle and in buffaloes is due to the fact that cattle produce more vigorous calves which also stand the climatic conditions better than buffalo calves.

Mortality of buffalo calves can be markedly reduced by improving the sanitary conditions, especially when artificial suckling is used; by raising the level of feeding and management; and by controlling epidemic diseases. Calf pens should be constructed to protect young calves from cold during winter, and crowding of calves should be avoided.

It is interesting to note that more than 80 per cent. of dead calves were lost before they reached 6 months of age (Table 1). This indicates that systems of rearing calves are responsible to a great extent for these losses. Unfortunately not all causes of death were diagnosed, and therefore it was not possible to determine all the diseases responsible. However, the most important diseases reported were pneumonia, digestive troubles, and navel infections.

Table 1 shows a loss of 17·4 per cent. for males compared with 15·6 per cent. for females, but this difference is not statistically significant. Davis [2] obtained similar results on dairy calves in the United States. As expected, the mortality rate of calves decreased with the advance in age (Table 1).

Effect of year and month of calving on mortality of calves. Table 2 shows the mortality rate of calves in the two herds of buffaloes for each of the last fifteen years.

TABLE 2. *Mortality Rate of Buffalo Calves in Different Years*

	Year and percentage mortality														
Station	*1940*	*'41*	*'42*	*'43*	*'44*	*'45*	*'46*	*'47*	*'48*	*'49*	*'50*	*'51*	*'52*	*'53*	*'54*
Sids	12·9	8·5	8·7	8·8	41·2	47·2	13·4	21·1	20·9	32·1	35·6	14·7	17·5	8·9	11·5
Sakha	15·2	21·0	27·9	38·1	52·1	50·8	36·2	31·8	36·7	35·8	59·8	32·0	44·0	28·0	27·8

This table shows how losses of calves varied from year to year. It is interesting to note that during the whole period calf mortality at Sakha was always higher than in the same year at Sids. The highest losses recorded at the two stations, in 1944, 1945, and 1950, were due to attacks of haemorrhagic septicaemia.

Table 3 shows the number and percentage of calves that died in different months of the year. The heaviest losses at both stations were during winter (November, December, January, and February). The mortality rate of calves during these four months was 52·2 per cent. at Sakha and 64·4 per cent. at Sids. It is interesting to note that calvings during winter months were 49·5 and 46 per cent. for Sakha and Sids respectively (Table 4).

The heavy losses of calves during the winter may have been due to many factors. Young calves may be exposed to cold weather especially at night, which increases the incidence of pneumonia. The crowding

TABLE 3. *Calf Losses by Months*

(*Average, 1940–54*)

Month	Sakha		Sids	
	No. of deaths	*Per cent.*	*No. of deaths*	*Per cent.*
January . . .	187	15·2	54	22·6
February . .	146	11·9	38	15·9
March . . .	109	8·9	22	9·2
April . . .	71	5·7	13	5·4
May . . .	51	4·3	14	5·9
June . . .	58	4·7	8	3·3
July . . .	66	5·4	13	5·4
August . . .	79	6·4	5	2·2
September . .	69	5·6	6	2·5
October . . .	83	6·8	4	1·7
November . .	121	9·9	24	10·0
December . .	187	15·2	38	15·9
Total . . .	1,227	100	239	100

TABLE 4. *Distribution of Births by Months*

(*Average, 1940–54*)

Month	Sakha		Sids	
	No. of births	*Per cent.*	*No. of births*	*Per cent.*
January . . .	456	13·6	182	15·2
February . .	353	10·6	128	10·7
March . . .	242	7·2	62	5·2
April . . .	166	4·9	57	4·7
May . . .	235	7·0	70	5·8
June . . .	136	4·1	41	3·4
July . . .	116	3·5	42	3·5
August . . .	168	5·0	63	5·2
September . .	324	9·7	67	5·6
October . . .	418	12·5	85	7·1
November . .	357	10·7	202	16·8
December . .	373	11·2	202	16·8
Total . . .	3,344	100	1,201	100

of calves during winter months, which is due to the high percentage of winter calvings, may be responsible for the spread of epidemic diseases. It is possible to reduce the losses during winter by protecting the calves during cold nights and by avoiding crowding. Extending the calving season for a longer period will also help in minimizing the losses.

Abortion in buffaloes. Calf losses due to abortion and stillbirth in the two herds were 1·1 per cent. (Table 5). Abortion and stillbirths have been reported to be the most serious factors which increase mortality rate of calves in dairy cattle; Davis [2] and Lassiter and Seath [1] have shown that calf losses due to these two factors ranged between 5 and 12 per cent., much higher than the above rate for buffaloes.

This discrepancy between percentage of abortion in cattle and in

buffaloes needs more investigation from the genetical, physiological, and veterinary aspects. Probably the frequency of genes responsible for congenital abortion is lower in buffaloes than in cattle, or perhaps early embryonic deaths occur more frequently in buffaloes. The susceptibility of buffaloes to contagious abortion, *Vibrio foetus vaginitis*, and other diseases which cause abortion should be studied.

Sex ratio in buffaloes. The sex ratio in 4,641 buffalo calves was such that males exceeded females significantly (Table 5) the respective percentages being 52 and 48.

TABLE 5. *Sex Ratio, Twinning, and Abortion in the Egyptian Buffalo*

Station	Births Total no.	Males		Females		Twin births		Abortions	
		No.	%	No.	%	No.	%	No.	%
Sids	1,203	613	51·3	583	48·7	2	0·1	7	0·6
Sakha	3,438	1,776	52·3	1,620	47·7	11	0·3	42	1·2
Total no. and average %	4,641	2,389	52·0	2,203	48·0	13	0·3	49	1·1

The sex ratio in dairy cattle has been studied by many workers in different countries [2, 3, 4]. Most of the data indicated that males exceeded females, especially when large numbers of animals are considered. The authors' results on buffaloes are in close agreement with those reported on dairy cattle abroad in this respect.

Twinning in buffaloes. In the 4,641 calves involved in this study there were thirteen sets of twins (Table 5). The twinning percentage in buffaloes thus amounted to 0·2. Reports on twinning percentage in dairy cattle indicate that it is higher than that in buffaloes. It has been shown by Arnold and Becker [4] that the twinning percentage in dairy cattle was on the average 3·4. The difference between cattle and buffaloes in this respect is not surprising since we are dealing with two different species. The low fertility of buffaloes may also be partly responsible for the low twinning percentage.

Twinning is not a desirable character in buffaloes or cattle, since twins are either born dead or are born smaller and weaker than single calves. Moreover, cows giving birth to twins usually have many troubles during parturition which may affect their production in the following lactations, besides a tendency towards infertility.

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BUFFALO BULLS IN EGYPT

A. A. EL-ITRIBY AND A. A. ASKER[1]

(*Animal and Poultry Breeding Department, Ministry of Agriculture, Cairo*)

Summary

This investigation was undertaken to study the age of buffalo bulls when first used at service, their productive life, the replacement rate, and reasons for disposal of bulls, in Egypt. Data collected from four experimental stations belonging to the Ministry of Agriculture where the bulls were raised were used in this work. Records on more than 600 bulls from 1942 to 1955 were utilized in this study.

It has been found that the average age of buffalo bulls when first used at service is $3{\cdot}7 \pm 0{\cdot}7$ years, while their average useful life was four and a half years. Of 611 bulls 62 per cent. were still in service at the end of 1954. Death accounted for 11·5 per cent. and culling for 26·5 per cent. of the bulls. Reasons for discarding bulls were bad disposition, sterility, old age, and low production of their dams after the first lactation. The annual replacement rate of buffalo bulls in this study was about 5 per cent.

THE buffalo is practically the main dairy animal in Egypt, since it excels the native cow in milk yield, butterfat percentage, and ability to utilize coarse food. It may also be used for work and the male calves are a good source for veal production.

Most of the farmers in Egypt cannot afford to keep a buffalo bull because they are small landholders who usually keep a few buffalo cows. Buffalo bulls used for service in most parts of the country are of inferior quality and of unknown milk-producing potentialities.

The Animal and Poultry Breeding Department of the Ministry of Agriculture, therefore, started in 1939 a breeding project to provide farmers with better bulls, free of charge, in an endeavour to raise the milk production of buffaloes in the country. This scheme was discussed in detail by Sidky [1]. Bulls from high-producing dams were raised at different experimental stations and were distributed to social centres, agricultural centres, co-operative farmers' organizations, and to landowners who keep buffaloes for milk production. Bulls are not kept more than three years in any centre and are then shifted to another centre, to avoid inbreeding.

The present investigation was therefore undertaken to gain some information on buffalo bulls in Egypt. Age of bulls when they are first used at service, average productive life, reasons for disposal, and replacement rate for buffalo bulls were studied. Such information is very valuable in a breeding programme.

Material

Breeding centres for buffalo bulls are located at four experimental stations, namely, Sakha, El Gemeiza, and Mahallet Mousa, in the Delta,

[1] Present address: Ein Shams University, Faculty of Agriculture, Sarai El Kobra, Cairo, Egypt.

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and Sids in Upper Egypt. Records kept at these stations on 611 bulls were utilized in this study. The information available in these records for each bull was: date of birth; date of first service; date and reason for disposal; and number of services for each month during the productive life of the bull. The milk yield during the first lactation of dams of bulls was also recorded.

Results

The average age of buffalo bulls when first used for service was $3{\cdot}7 \pm 0{\cdot}70$ years. This average was based on 551 bulls whose date of birth as well as date of first service were known. Some bulls were used first for service when they were 5·5 years old, while others were used at the age of 9 months. An analysis of the age of bulls raised at the different stations showed that there were no significant differences between the average ages when first used for service, for the bulls produced at the four stations, viz.—Mahallet Mousa $3{\cdot}7 \pm 0{\cdot}8$; El Gemeiza $3{\cdot}5 \pm 0{\cdot}4$; Sakha $3{\cdot}6 \pm 0{\cdot}5$; Sids $3{\cdot}7 \pm 0{\cdot}6$ years.

To study the useful life of buffalo bulls, they were classified into two groups; the first group comprises those which were disposed of up to December 1954, while the second group includes bulls which are still in service. One hundred and sixty-two bulls were discarded during the period of study (1942–55); their average age was 7·7 years. The average productive life of these bulls was thus four years. A few bulls were used for less than a month, while the useful life of others was more than nine years. By the end of 1954, 389 bulls were still in use at different centres, of an average age of 8·7 years, which indicates that they were used for five years. The data collected from different stations showed that bulls produced from some stations were used for a longer period than those from others; viz.—Mahallet Mousa $5{\cdot}1 \pm 0{\cdot}6$; El Gemeiza $7{\cdot}0 \pm 0{\cdot}9$; Sakha $5{\cdot}4 \pm 0{\cdot}8$; Sids $3{\cdot}2 \pm 0{\cdot}3$; the differences between stations in this respect were statistically significant. The average productive life for all bulls distributed by the Ministry was four and a half years.

The numbers and percentages of bulls that died or were disposed of during the period of the study showed that out of 611 bulls, 380 or 62·0 per cent. were still in service, while 70 (11·5 per cent.) died and 161 (26·5 per cent.) were sold for various reasons, mainly viciousness, inability to fertilize or copulate, inability to mount females, old age, and low production of their dams after their first lactation. Table 1 shows the percentage of bulls that were culled for different reasons.

TABLE 1. *Disposal of Buffalo Bulls*

Reasons for culling	*Percentage*
Bad disposition. . . .	8·6
Sterility for different reasons .	21·0
Senility	32·1
Low production of dams . .	38·3

Calculation of the replacement rate for buffalo bulls was based on the fact that of the bulls included in this study 38 per cent. had died or were

sold and about 95 per cent. were born in a period of eight years (1942–50). This corresponds to an annual replacement rate of about 5 per cent.

Discussion

The low milk production of both Egyptian native cattle and buffaloes compared with European cattle is a serious problem which needs steady and continuous attack. One of the solutions sought for such improvement was the use of bulls of superior germ-plasm on the farmers' cows in the country. Such bulls were distributed at the different agricultural centres.

This investigation has shown that the average age of buffalo bulls when first used for service is 3·7 years, which is much higher than the 12 to 15 months which is the average for bulls belonging to different dairy breeds in temperate countries. Using buffalo bulls at such a higher age will lead to an increase in the generation interval and consequently the genetic gain per year is decreased. Asker and Ragab [2] and Khishen [3] found that the generation interval in the Egyptian buffalo ranged between six and seven years, which is longer than that reported for dairy cattle [4]. Undoubtedly, using bulls for service at an earlier age will lead to a smaller generation interval and increased productive life of bulls.

Smith and Robinson [5] found the average productive life of pedigree bulls for beef and dairy cattle in England to be 1·85 years, while Wright [6] concluded that dairy bulls are used for service for a period of 2·25 years. In the present study the average productive life for buffalo bulls, 4·5 years, is thus longer than that reported for dairy bulls in England. This is probably due to the small number of buffalo bulls available for service in Egypt in relation to the population of buffaloes in the country. The breeder, therefore, had to use bulls as long as they can serve females successfully.

Of course, increasing the productive life of bulls will decrease the replacement rate, and consequently the selection differential will be increased. Moreover, increasing the serviceable life of bulls will give breeders more opportunity to determine the bull's potentialities for milk production, through the yield of his daughters, which is the most reliable index of milk-transmitting ability.

Although much work has been reported on the wastage of dairy cows, very little has been reported in this regard for bulls. Lagerlof [7] found that about 13 per cent. of Swedish bulls were culled because of sterility, while in New Zealand 9·3 per cent. of 1,489 bulls were sold as sterile [8]. Becker *et al.* [9] made a detailed study of reasons for disposal of dairy bulls in the United States and Canada. They found that about 25 per cent. of the bulls became sterile, 14 per cent. were discarded because of bad disposition, 21 per cent. died for various reasons, and 10 per cent. were culled because of the low production of their daughters.

The present study shows that 21 per cent. of buffalo bulls were discarded because of various types of infertility, which is higher than that reported by other workers. The reasons for such a high level of sterility of bulls should be investigated from the physiological, genetical, and husbandry aspects. It should be pointed out here that buffalo bulls

in Egypt are generally used very intensively in a short period of time, which may lead to their exhaustion, and consequently to the production of semen of low quality. This analysis shows that about 70 per cent. of buffaloes are served during the comparatively short period of November, December, January, and February. This fact coupled with the small number of bulls available for service in Egypt will lead to sterility of males.

Sterility of bulls for genetic reasons has been reported in dairy cattle, but nothing is known about this for buffaloes. Care in feeding and management of bulls will reduce sterility due to husbandry causes. The percentage of bulls discarded because of bad disposition can be minimized by using safety breeding chutes that can be built in bull pens.

About one-third of the buffalo bulls were culled because of the low production of their dams after the first lactation, which is a high proportion. Using only the first lactation of a buffalo for estimating her producing ability is not very reliable, since the repeatability of milk yield in buffalo was found to be rather smaller than most figures obtained for dairy cattle [10, 11]. However, the method now used for selecting bulls is the production of their daughters rather than the production of their dams. Type of dam and regularity in breeding are also taken into consideration during selection. The average milk yield of dams used for producing buffalo bulls in this study was 4,460 pounds, compared to 2,500 pounds for the average of the population in the country.

This study has shown that about 11·5 per cent. of bulls distributed by the Ministry died while in service. Unfortunately, not all causes of death were definitely diagnosed, and therefore it was not possible to estimate the percentage of deaths due to different diseases. However, Becker *et al.* [9] mentioned that 11 per cent. of the bulls they studied died from disease, while accidents and injuries were responsible for a further 10 per cent.

The replacement rate of bulls found in this study is very close to that reported by Lush [4] on dairy cattle. Smith and Robinson [5], studying the replacement percentage of bulls in pedigree dairy herds in Great Britain, reported a very high figure. It would be expected that in pedigree herds a high percentage of bulls are discarded to avoid inbreeding. Becker *et al.* [9] concluded that about 34·5 per cent. of bulls in small herds were culled for this reason.

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SOME FEATURES OF THE MINERAL COMPOSITION OF MOLASSED BEET PULP

A. EDEN

(*National Agricultural Advisory Service, Anstey Hall, Trumpington, Cambridge*)

Summary

Analysis of 244 samples of molassed beet pulp from eighteen factories in the course of two seasons showed an average moisture content of 10·1 per cent., 6·4 per cent. total ash, 0·8 per cent. silicious matter, 0·75 per cent. CaO, and 0·14 per cent. P_2O_5. The phosphorus content of beet pulp was found to be much less variable than the calcium content.

DRIED sugar-beet pulp, plain or molassed, is an important item in the dietary of young cattle, stores, beef cattle, and dairy cows in many parts of the country. This particularly applies to the predominantly arable districts where sugar-beet is a normal feature of the cropping. In respect of its broad nutritive value beet pulp is very similar to oats, for ruminants at least, although it has a rather lower content of digestible protein. Its mineral make-up, however, is rather poor and unbalanced, and it is particularly low in phosphorus content. In many of the circumstances in which it is used in association with low-phosphorus roughages such as barley straw and over-mature hay, unsupplemented by phosphate mineral supplements, the low intake of phosphorus may lead to a variety of problems in livestock.

The limited data for the mineral composition of beet pulp derive from analyses carried out many years ago. The figures most commonly quoted are those of Woodman [1], namely, that, at a moisture content of 10 per cent., molassed beet pulp contains 5·5 per cent. total ash, including 1·2 per cent. CaO and 0·17 per cent. P_2O_5. Recalculation of data derived from American sources quoted by Morrison [2] indicates that at a similar moisture content beet pulp contains 5·1 per cent. total ash with 0·71 per cent. CaO and 0·16 per cent. P_2O_5, whereas Linton and Williamson [3] give figures of 4·0 per cent. total ash, including 0·91 per cent. CaO and 0·26 per cent. P_2O_5 when recalculated to the 10 per cent. moisture basis, though in a later edition [4] of this book the analyses quoted are as in [1]. Unfortunately there is little information available on the number of samples involved in arriving at such figures, and computations of the gross mineral intakes of animals on particular diets, and *a fortiori* of calcium: phosphorus intake ratios based on such figures, may give rise to some misleading conclusions.

Moreover, examination of occasional samples of pulp has indicated figures that differ appreciably from those quoted above, generally in the direction of revealing an even poorer content of calcium and phosphorus, and this has led to the question whether modern sugar-beet-processing

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methods or different varieties of beet give rise to products that have an appreciably different composition from those on which the older data are based. Accordingly it was made possible through the good offices of Mr. J. C. Macdonald of the British Sugar Corporation, Ltd., to examine samples of molassed pulp from eighteen factories operating in Great Britain at regular intervals throughout the course of two autumn sugar-beet-processing campaigns.

The samples were examined for moisture content on arrival and subsequently analysed for total and hydrochloric acid-insoluble ash, calcium (as CaO) and phosphorus (as P_2O_5) by conventional or slight modifications of conventional methods. In all 244 samples were received for analysis, and the results are set out in Table 1, giving the mean data for each factory (specified by letter index).

TABLE 1. *Composition of Molassed Beet Pulp Samples*

Factory	*Number of samples*	*Average moisture content as received* %	*Average mineral composition. Dry-matter basis*			
			Total ash %	HCl-*insoluble ash* %	CaO %	P_2O_5 %
A	16	11·06	7·84	0·87	0·91	0·15
B	16	9·11	7·38	0·76	0·76	0·16
C	23	10·14	6·87	0·31	1·13	0·15
D	11	10·90	7·30	1·01	0·80	0·16
E	15	10·22	6·51	0·74	0·87	0·16
F	14	10·78	7·07	1·00	1·09	0·15
G	14	10·44	7·42	0·66	0·85	0·15
H	15	9·55	8·15	1·91	0·89	0·15
I	12	8·62	6·59	0·49	0·70	c 16
J	10	8·98	6·46	0·50	1·20	0·17
K	5	9·42	6·78	0·76	0·67	0·15
L	13	10·22	7·76	1·55	0·63	0·16
M	16	10·10	7·81	1·39	0·61	0·16
N	14	10·00	6·70	0·94	0·80	0·16
O	13	8·54	6·60	0·64	0·82	0·15
P	13	11·17	6·68	0·80	0·60	0·16
Q	13	9·56	7·18	0·72	0·80	0·16
R	11	11·67	5·59	0·45	0·61	0·16
Total	244	Mean 10·09	7·09	0·87	0·83	0·16

Comments on Table 1. The mean figure for the moisture content of molassed beet pulp agrees with that normally quoted. The mean total-ash figure on the dry-matter basis was 7·09 per cent., but the extreme range of all the samples examined was from 4·7 to 10·9 per cent. (the latter sample contained the high figure of 4·9 per cent. silicious matter), although 91 per cent. of the total samples showed figures between 6·0 and 8·9 per cent. The amounts of silicious matter (HCl-insoluble ash) were more variable, ranging from 0·1 to 4·9 per cent., but over 40 per cent. of the samples showed values not exceeding 0·5 per cent.

The phosphorus content was remarkably constant. Extreme values

of 0·12 and 0·22 per cent. were found, but nearly 86 per cent. of the samples had P_2O_5 values of between 0·14 and 0·19 per cent. on the dry matter. These figures confirm the very low phosphorus status of beet pulp as well as its relative constancy, despite the wide range of soil conditions on which the crops were grown. Referred to a standard moisture content of 10 per cent., the P_2O_5 content of beet pulp was on average only 0·14 per cent.

The lime content was, however, rather more variable. The extreme range of all figures was from 0·48 to 1·33 per cent. on the dry-matter basis, but the range of values in samples emanating from individual factories was much narrower. The CaO data would appear to fall into three main groups: (1) from 0·61 to 0·70 per cent.; (2) from 0·76 to 0·91 per cent.; and (3) from 1·09 to 1·20 per cent. It is impossible to say from the present data whether these rather arbitrary groupings reflect the different soils and soil conditions under which the crops were grown or the washing techniques employed at the various factories. The sugar-beet crop is sensitive to acid soil conditions, and normally the crop is grown on soils that have small or large reserves of free calcium carbonate, either naturally present or applied by liming materials.

An attempt was made to see whether there was any correlation between the levels of CaO content of the pulp and the geographical areas from which the beet derived, but this showed no clear-cut indication. Generally the lower values tended to be associated with the more northerly- and westerly-situated factories.

It would therefore appear from the present study, which has been concerned with the composition of beet pulp over two seasons from all the factories where it is produced in Great Britain, that the average percentage composition of molassed beet pulp as fed is: moisture, 10 per cent.; total ash 6·4 per cent.; silicious matter, 0·8 per cent.; calcium as CaO, 0·75 per cent.; and phosphorus as P_2O_5, 0·14 per cent. These data, when compared with those quoted in H.M.S.O. Bulletin No. 48 [1], show a higher total ash, an appreciably lower CaO and a slightly lower P_2O_5 content, and in respect of lime and phosphorus contents agree more nearly with the American data. Nevertheless, some of the CaO figures obtained in the present study are very close to the figures quoted in the Bulletin, and the results as a whole show the very marked variability of this constituent. The data further illustrate the need for great care in interpreting calculations of the mineral intake of farm animals from standard figures. This need becomes intensified when hypotheses are built up on calculations of calcium: phosphorus ratios. Ratios based on the mean CaO : P_2O_5 ratios from the different factories vary from 3·8 to 7·7, and on individual results from 2·8 to 9·1, compared with the general mean ratio of around 5·2.

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A NOTE ON THE IDENTITY OF A BACTERIUM CAUSING STALK ROT AND LEAF BLIGHT OF MAIZE IN SOUTHERN RHODESIA

K. A. SABET

(*Agricultural Biology Department, University of Khartoum, Sudan*)

Summary

A bacterium causing stalk rot and leaf blight of maize in Southern Rhodesia has been found closely to resemble *Erwinia carotovora* f. sp. *zeae* Sabet, the cause of a similar disease of maize and sorghum in Egypt, in its cultural, morphological and biochemical characters. Both organisms produce the same symptoms and effects on their hosts and rot storage tissues under laboratory conditions. It is concluded that the disease in Southern Rhodesia is caused by the same organism.

In a previous investigation [1], a bacterial disease causing stalk rot and leaf blight of maize in Egypt was attributed to *Erwinia carotovora* f. sp. *zeae* Sabet. This organism resembles *E. carotovora* but differs mainly in its ability to infect additional hosts i.e. certain members of the Graminae of the warmer regions. It was further pointed out that the Egyptian maize pathogen differs from *E. dissolvens* Rosen [2], the alleged cause of a similar disease of maize and sweet corn in U.S.A., in certain cultural and biochemical characters as well as being a true soft-rot organism, thus differing again from *E. dissolvens* which, according to Waldee [3], does not cause any rot in vegetables or produce the enzyme protopectinase. In India, a similar disease of maize was reported by Prasad [4], and attributed to *E. dissolvens* on symptoms only. Ludbrook [5], described a bacterium which appears to cause the same or a similar disease in Australia.

Through the courtesy of Dr. W. J. Dowson, Botany School, Cambridge, a culture of a bacterium causing stalk rot of maize in Southern Rhodesia was received by the author for examination. This culture was compared with a recent isolate of *E. carotovora* f. sp. *zeae* from affected maize plants grown near Cairo.

Characters of the Bacteria

The methods used to characterize the two isolates (one Egyptian and one Rhodesian) were those generally employed for this purpose. Action on carbon sources was tested in 1 per cent. solutions of the carbohydrates in peptone water with brom-cresol purple as indicator. The cultures were kept at 30° C. for 35 days.

Both isolates proved to be identical in cultural, morphological, and staining characters. In its biochemical characters, the Rhodesian bacterium was generally a slower acid and gas producer than the Egyptian strain previously described by Sabet [1]. This was more so in the case of glycerol, in which production of acid was rather doubtful and delayed for 30–35 days.

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Cross Inoculations

The two isolates were inoculated into four varieties of maize namely: K55 and Eg102 (very susceptible varieties) and K64 and G76 (relatively resistant). Inoculations were made into potted plants 35–40 days old either (1) by spraying the plants with a thick watery suspension of the bacteria; or (2) by the insertion into the stems of a flamed needle charged with the bacterial growth. Inoculated plants were kept under glass bell jars for 48 hours after inoculation.

Both isolates produced similar disease symptoms on maize. Long water-soaked lesions developed on the leaves after 48 hours. The affected parts shrivelled and died within 5–8 days. Inoculated stems showed signs of rot after 48 hours. The rot extended rapidly in all directions and the stems collapsed completely after 4–10 days. Maize varieties which are normally regarded as relatively resistant to the Egyptian strain, showed the same degree of resistance to the Rhodesian strain. This was indicated by the smaller lesions produced on the leaves and the slower development of the disease in the stems of such varieties (K64 and G76).

When inoculated into sorghum and sweet corn in the same way, the two bacterial isolates produced effects on both hosts similar to those on maize.

The two isolates also rotted slices of raw potato tubers and vegetable marrow fruits cut under aseptic conditions and kept in sterile Petri dishes to which sterile water was added. The rot developed rapidly at 30° C. and covered the cut surface of the tissues, 4–5 cm. in diameter, in 2–3 days.

Conclusion

It is evident that the Rhodesian bacterium closely resembles *E. carotovora* f. sp. *zeae*. The slowness in acid and gas production by the former organism as compared with the latter is well within strain differences. More important is that they produce the same disease in maize, sorghum, and sweet corn, and rot storage tissues. The Rhodesian pathogen is thus identified as *E. carotovora* f. sp. *zeae*.

The bacterium causing top rot of maize, sorghum, and sweet corn, as described by Ludbrook [5], has many characters in common with the two strains just studied. This suggests that *E. carotovora* f. sp. *zeae* is probably also the cause of the disease in Australia.

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STUDIES OF THE GROWTH OF CEREALS ON SEED-BEDS PREPARED BY DRY-SIEVING OF THE SOIL

R. S. EDWARDS

(*Department of Agriculture, University College of Wales, Aberystwyth*)

WITH PLATE I

Summary

Experiments carried out at Aberystwyth between 1951 and 1956 on the emergence of spring barley and winter oats are described. The cereals were sown in seed-beds prepared by dry-sieving the soil and then placing the separates in plots excavated in the field. A description is given of the techniques used for the preparation of the plots. The effects of aggregate-size of soil separates, sowing date, and seed-bed compaction, on both the sowing-to-emergence interval and the percentage emergence were studied. Records of the soil temperatures and of the soil suction pressures were kept and the relationships between these environmental factors and certain features of plant behaviour are discussed.

THESE studies were initiated after noting the wide divergence of opinion among practising farmers on the one hand and many agricultural scientists on the other, on the sensitiveness of cereals to differences in the physical characteristics of the seed-bed in which they are sown. For example, most growers of malting barley have always insisted that a fine firm seed-bed is absolutely necessary for the success of the crop, both as regards yield and the quality of the grain. This traditional belief is so widely held and of such standing that it must command considerable respect. Data collected from farmers during a survey carried out by workers at Rothamsted Experimental Station were, however, commented on by Russell [1] in these terms: 'This table shows the surprising result, that taken over the fields available, both the yield and the quality of the malting barley were independent of the suitability of the seed-bed for malting barley as judged by the farmer himself.' The two points of view are well expressed in papers read to the Institution of British Agricultural Engineers by Wedderspoon and Russell [2] in 1945. Many experiments comparing cereal growth on seed-beds produced by different cultivation techniques have tended to show that these crops are surprisingly insensitive to variations in the method of seed-bed preparation over a wide range of soil types provided that the effects of the cultivations on the competition of weeds with the crop are taken into account [3, 4, 5, 6]. It has also been observed frequently that differences in the early stages of growth of the crops, attributable to different cultivation treatments on the seed-bed, are not reflected in the final yield [3, 4]. Work by Lawton and Browning in the United States of America [7] and by Singh [8] in Britain tends to show that responses to different cultivation treatments may be expected only on poor soils having less favourable physical conditions. The literature on the relations between plant growth, soil structure, and cultivation practices has been reviewed recently by Singh [8] and Singh and Pollard [9]. Thus, while

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many scientific observations tend to show that the cereals are not very responsive to the normal range of variation in the physical state of the seed-bed, most farmers firmly believe that an ideal exists and that any departure from it has detrimental effects of considerable magnitude on the yield and quality of the crops. These studies were designed in an attempt to discover to what extent variations in the size-distribution of aggregates and solid particles in the seed-bed affected the emergence, development, and fruition of two cereals—spring barley and winter oats.

Since this paper is the first of a series it has been considered appropriate to make, at this point, some general remarks on the whole work.

These experimental results were obtained from investigations carried out at Aberystwyth on well-drained medium-loam soils of the Corwen series. In the first instance the experiments were confined to spring-sown barley, since this cereal is, according to tradition, responsive to seed-bed differences. An established malting variety, Spratt Archer, was chosen for a similar reason. Later, when the investigations were extended to include autumn-sown cereals, winter oats were chosen. This crop seemed more suitable than either winter barley or winter wheat, which are but rarely grown in west Wales. The variety S.147 was used for one season but, as it suffered from severe frost-killing, it was replaced by S.172 in all subsequent work. This latter variety has been shown to be more frost-resistant under local conditions (D. J. Griffiths and J. D. Hayes, private communication). It was decided to sow these cereals in seed-beds prepared by dry sieving the soil and placing the resultant separates in pits or trenches in the open, these being excavated to the usual plough depth for the district, i.e. about 6 inches. The sieving method for producing different seed-beds was adopted because it appeared to have the following advantages:

(i) By sieving it is possible to produce seed-beds which are obviously different one from another and which differ in a graduated manner.
(ii) Extreme conditions of roughness or fineness of tilth are attainable.
(iii) Within limits, which have been discussed elsewhere, [10] the seed-beds can be reproduced in so far as size distribution of aggregates is concerned.

The disadvantages inherent in this method are:

(i) The plots have, of necessity, to be smaller than is desirable for accurate assessment of yield.
(ii) The seed-beds are not directly comparable with tilths produced by conventional means.
(iii) The act of sieving by its very nature may have effects apart from separation of aggregate sizes; for example, the concentration of stones in certain fractions may appreciably reduce the volume of effective soil in the plot; further the sieve may redistribute weed seeds.

Nevertheless, it is believed that a study of the behaviour of the plants under these exaggerated conditions may be helpful in an appreciation of the general problem of plant response to tilths.

Data collected

From these experiments data relative to the following have been collected and analysed:

Emergence

Length of the interval between sowing and the mean day of emergence.
The number of coleoptiles emerged per 100 seeds sown.

Survival and development of plants

Yield of grain and straw

Number of fruitful culms per plant.
Grains per culm.
Thousand-grain weight.
Percentage nitrogen in the barley grain.
Yield of grain.
Length of straw.
Yield of straw.

Factors of the environment

Percentage moisture in the soil at the time of sowing.
Soil temperature in the seed-beds.
Suction pressure of the soil in seed-beds.
Pore-space distribution in these soils.
Mechanical and chemical analyses of the soils used.

Emergence

In most investigations on the growth of cereals on different seed-beds little attention has been paid to the actual emergence of the plants apart from comparisons between the stands which finally result. The Rothamsted workers noted that emergence appeared to be faster and more complete on the fine loose seed-beds produced by rotary tillage [3]. DeMent and his co-workers [11] showed that soil conditioners which prevented the formation of a hard surface crust increased the percentage emergence of maize, soya beans, and turnips on a silt loam. They also showed that speed of emergence was greater where conditioners were used. These results suggest that mechanical impedence of emergence may be an important factor determining the final stand. Work in Japan [12] on a volcanic soil showed that the smaller the aggregate size the narrower was the range of soil-moisture content which permitted a high percentage emergence of wheat. It was suggested that the factors inhibiting emergence in fine soil ($< 0{\cdot}25$ mm.) were low soil-oxygen content at high moisture content and surface crusting at low moisture content. It seems probable that exact information on the percentage emergence and speed of emergence in the field is sparse because of the difficulty of estimating the number of seeds sown when the usual seed drill is employed. The techniques described below have involved the

hand planting of a known number of seeds in the plots so that exact measurement of the percentage emergence and of the sowing–emergence interval has been possible.

Experimental Method

Locations, dates, and layouts. The experiments were begun in spring 1951 in the Agricultural Botany Experimental Gardens at Aberystwyth when, in a pilot experiment, Spratt Archer spring barley was sown on thirty plots laid out in a randomized-block design; the six soil-separate aggregate-size treatments were allocated at random in each of five blocks. In autumn 1953 a pilot experiment on S.147 winter oats was located on the U.C.W. College Farm, where all the subsequent experiments were conducted. This pilot experiment consisted of twenty-four plots, six soil-separate aggregate-size treatments being randomized in each of four blocks. The spring 1954 and 1955 experiments on Spratt Archer barley and the autumn 1954 and 1955 experiments on S.172 winter oats were all split-plot layouts in which the following three treatment-groups were incorporated:

(*a*) Three dates of sowing: mid-March, early April, late April in the spring experiments; and late September, mid-October, early November in the autumn experiments.
(*b*) Five aggregate-sizes of soil separates, and unsieved soil.
(*c*) Two degrees of consolidation of the soil in the plot.

Each treatment (*a*) was allocated to a whole block and all combinations of (*b*) and (*c*) were allocated at random to the twelve plots of each block. Twofold replication gave seventy-two plots per experiment. The spring 1956 experiment with Spratt Archer barley was laid down for a particular purpose (weed control) and was an addition to the above planned programme. It consisted of a split-plot layout similar to the 1954–5 series but excluding the consolidation treatment. The choice of layout was governed by two factors. First, the quantity of soil which could be handled and sieved was limited; this controlled the number and size of the plots. Second, the plots had to be accessible for transport of soil from the plots to the sieve and back again.

Excavation and handling of the soil. For the 1951 and 1953 pilot experiments plots 2 ft. 2 in. square were excavated to a depth of 6 in. leaving paths 2 ft. wide between the plots. The soil was removed to an area alongside the plots and spread out to dry, being covered with a tarpaulin when rain appeared likely. In the remaining experiments two trenches each 3 ft. 2 in. wide and 31 ft. 4 in. long by 6 in. deep were excavated for each time-of-sowing treatment (making six trenches per experiment). The trenches were then divided into plots by wedging boards (3 ft. 2 in. $\times$ 6 in. $\times$ 1 in.) across the trench 2 ft. 2 in. apart. This gave the necessary twelve plots per block and a guard plot at each end. This method had advantages compared with that previously used in that it materially reduced the border effect of light at the row ends, was less laborious and yet achieved complete root separation down to the depth of the experimental seed-beds. The excavated soil was heaped alongside

the trenches (which were 4 ft. apart) and covered with galvanized iron sheets when necessary.

Sieving operations. Sieving commenced when a test showed that the soil was dry enough to pass the screens without clogging the meshes. With experience this could be judged in the same way as a farmer judges whether or not a field is dry enough for cultivation. Samples were taken and oven-dried at 105° C. to constant weight at each sowing to obtain the soil-moisture percentages which are shown in Table 1.

TABLE 1. *Soil-Moisture Percentage at Time of Sowing (based on oven-dry weight)*

Time of sowing	*Spring 1951*	*Autumn 1953*	*Spring 1954*	*Autumn 1954*	*Spring 1955*	*Autumn 1955*	*Spring 1956*
Early .	..	..	32·4	No data	33·1	15·0	33·0
Mid .	29·3	30·8	33·9	35·1	34·8	22·8	29·6
Late .	..	..	21·9	33·1	30·8	32·4	24·6

In the pilot experiments the excavated soils were passed through a series of hand-operated reciprocating screens. In the main experiments 1954–6 the soils were first passed through a ½-in. hand-operated screen to remove large stones and trash and then separated by the mechanical sieve described in a previous paper [10]. The aperture sizes of the screens used in both manual and mechanical sieving are given in Table 2.

TABLE 2. *Size and Shape of the Apertures in the Screens used for Experiments 1951–6*

Experiments	*Size of apertures of screens*
1951 (Pilot)	.. ⅛"* ¼"* ⅜"* ½"* ¾"*
1953 (Pilot)	1 mm.* ⅛"* ¼"* ⅜"* ½"* ..
1954–6	1 mm.* ⅛"† ¼"† ⅜"† ½"* ..

* Square-hole wire-mesh screens. † Round-hole punched-metal screens.

The choice of the aperture sizes of the screens used was determined, to a great extent, by the nature of the soil on which the work was carried out. Screen-aperture sizes smaller than 1 mm. were impracticable because the rate of separation was too slow and sufficient soil could not be sieved in the time available. The upper limit of aperture size was determined by these facts: first, that with this soil a large quantity of extra soil had to be sieved to obtain enough of any fraction with aggregates above ½-in. diameter; second, that it became impossible to achieve a uniform depth of sowing in seed-beds made up of very large clods. Punched-metal screens with round holes were used for the larger sizes in the machine sieve (in preference to woven wire or square-hole punched metal) because experience had shown that round holes were much less liable to blockage by stones and were easier to clean. The high effective sieving area of woven wire when compared with punched metal determined that the former should be chosen for the finest screen since the

output of this screen was the factor which limited the sieving capacity of the machine as a whole.

Seed-bed layout and sowing techniques. The sieving operation produced soil separates with five aggregate-sizes which, together with soil similarly excavated and stored but not sieved, made up the six soil treatments. These were transported to the excavated plots and allocated according to the planned layout. Each plot was filled to a depth of $4\frac{1}{2}$ in. with its appropriate separate (or unsieved soil) and the surface was levelled. All seed used throughout was dusted with organo-mercuric fungicide and was tested for germination capacity, which on no occasion fell below 95 per cent. In the pilot experiments 1951 and 1953 four rows of seed were placed on the levelled surface at an inter-row spacing of 6 in., the outside rows being 4 in. from the plot edge. By laying the seeds alongside a ruler it was possible to place them 1 in. apart in the row, each row having twenty-five seeds. In the main experiments 1954–6 six rows were planted at the same spacing, allowing four counting rows with a discard row on each side. Sowing was facilitated in these experiments by using a sowing device. This consisted of a board 2 in. wide and 26 in. long with twenty-five holes $\frac{3}{8}$ in. diameter bored through it 1 in. apart centre-to-centre. In the holes were fitted twenty-five small metal funnels into each of which a seed was dropped after the device had been placed on the plot surface (Fig. 1, Plate 1). A compound fertilizer of composition 12 per cent. N, 12 per cent. P_2O_5, 15 per cent. K_2O was sprinkled along the rows of seeds before covering, at a rate equivalent to 200 lb./acre calculated on a length-of-row basis.

To cover the seeds a wooden frame, equal in size to the plot and $1\frac{1}{2}$ in. deep, was placed on the level surface of the plot and carefully filled with the appropriate soil. A straight edge placed on the upper edge of the frame ensured an even cover of $1\frac{1}{2}$ in. over the whole plot (Fig. 2, Plate 1).

The consolidation treatment which was applied to half of the plots in the 1954–5 experiments was carried out as follows. The appropriate soil separate was placed in the plot and pressed down by attaching a board 10×6 in. to the sole of the operator's boot and applying this to the surface with an even transference of weight, giving a pressure of about 3 lb. sq./in. With practice an even pressure could be applied over the whole surface by this means. After sowing and covering the surface was again pressed in the same way.

In the 1954–6 experiments a Bourdon-gauge-type tensiometer together with one 2-in. and one 4-in. depth soil thermometer was placed in each of the twelve plots making up one replicate block at any given sowing date. These instruments were transferred to the corresponding plots laid down at the next time of sowing. The plots were finally covered with $\frac{1}{2}$-in. wire netting to exclude birds, &c., and, as a result of experience in 1951 and 1953, were sprinkled with metaldehyde bait to control slugs.

Treatment of data. The coleoptiles which emerged were counted daily over the whole period of emergence. These counts yielded information on two aspects of emergence.

(*a*) The length of the interval between sowing and emergence. Rather

than use the emergence of the first coleoptile which became visible in a plot as the end point of this period, the 'mean day of emergence' was calculated as follows: the days were numbered, the day of sowing being Day 1, the next Day 2, and so on. The number of coleoptiles emerging on a plot in any day was multiplied by the day number and the products summed over the whole period of emergence. This total divided by the total number of emergences on the plot gave the mean day of emergence for that plot. These figures represent the mean interval between sowing and emergence but the term 'Mean Day of Emergence' or 'M.D.E.' has been used in this sense throughout.

(*b*) The total number of coleoptiles emerging per 100 seeds sown, which has been named 'Percentage Emergence'. In the statistical analysis of this item the original percentages have been transformed to degrees using a table of angular transformations [13]. Both the original and transformed means are given in the results but the 'least significant difference' (L.S.D.) figures apply to the latter only.

The data on survival and development of the plants, on yields of grain and straw, and on pore-space distribution (see p. 169) will be dealt with in later papers.

Results

Pilot experiment on Spratt Archer barley 1951

The plots were sown on 5 April and the first coleoptiles emerged on 17 April. The mean day of emergence was calculated as described above and the mean values for the various treatments are shown in Table 3.

TABLE 3. *The Effect of Aggregate-Size of Soil Separate on the Mean Day of Emergence* (*Means of five plots*)

Aggregate-size of separate	$\frac{1}{8}$″	$\frac{1}{8}$″–$\frac{1}{4}$″	$\frac{1}{4}$″–$\frac{3}{8}$″	$\frac{3}{8}$″–$\frac{1}{2}$″	$\frac{1}{2}$″–$\frac{3}{4}$″	*unsieved*
M.D.E.	13·63	13·77	14·92	15·30	16·17	15·36

L.S.D. (P = 0·05) between means: 0·49.
„ (P = 0·01) „ „ 0·67.

This table indicates that emergence was significantly earlier in fine plots whereas a greater proportion of plants emerged on later days in coarse plots.

The mean numbers of coleoptiles which emerged per 100 seeds sown are shown in Table 4.

TABLE 4. *The Effect of Aggregate-Size of Soil Separate on the Number of Coleoptiles Emerged per 100 Seeds Sown* (*Means of five plots*)

Aggregate-size of separate	$\frac{1}{8}$″	$\frac{1}{8}$″–$\frac{1}{4}$″	$\frac{1}{4}$″–$\frac{3}{8}$″	$\frac{3}{8}$″–$\frac{1}{2}$″	$\frac{1}{2}$″–$\frac{3}{4}$″	*unsieved*
Percentages	96·4	92·6	57·0	50·8	44·0	64·0
Degrees	80·4	74·3	49·1	45·5	41·6	53·2

L.S.D. (P = 0·05) between means: 8·07 degrees.
„ (P = 0·01) „ „ 11·01 „

The emergence of the barley was greatly influenced by the aggregate-size of the separates making up the seed-beds. The highest percentage emergence occurred on the finer plots and the lowest on the coarser ones, with unsieved soil in an intermediate position.

Pilot Experiment on S.147 winter oats 1953

Plots were sown on 20 October and the first coleoptiles emerged on 30 October.

The mean-day-of-emergence values under the various soil treatments are shown in Table 5.

TABLE 5. *The Effect of Aggregate-Size of Soil Separate on the Mean Day of Emergence* (*Means of four plots*)

Aggregate-size of separate	*1 mm.*	*1 mm.–⅛″*	⅛″–¼″	¼″–⅜″	⅜″–½″	*unsieved*
M.D.E.	13·44	14·34	15·40	15·51	16·18	15·37

L.S.D. (P = 0·05) between means: 0·89.

This indicates that, as in the previous experiment, the coarser the plot the later was the mean day of emergence.

The percentage emergence is shown in Table 6.

TABLE 6. *The Effect of Aggregate-Size of Soil Separate on the Number of Coleoptiles Emerged per 100 Seeds Sown* (*Means of four plots*)

Aggregate-size of separate	*1 mm.*	*1 mm.–⅛″*	⅛″–¼″	¼″–⅜″	⅜″–½″	*unsieved*
Percentages	73·0	60·0	58·7	49·5	55·0	58·7
Degrees	58·8	50·9	50·2	44·7	47·9	50·0

L.S.D. (P = 0·05) between means: 8·1 degrees.

The finest plots gave a significantly higher percentage germination than all other treatments except the next finest. The general level of germination was low.

These two pilot experiments provided experience in the technique of preparation and layout of plots of sieved soil and the results gave some indication of the reaction of the cereals used to such seed-beds. However, differences in percentage emergence as great as those in the 1951 experiment were found, later, to be exceptional. This point will be elaborated in the final discussion.

Experiments 1954–6

At the commencement of the main series of experiments samples of the unsieved soil and of the separates were submitted for mechanical and chemical analysis with the following results:

TABLE 7. *Mechanical and Chemical Analysis of Whole Soil and Soil Separates from Experimental Field, 1954–6*

Aggregate-size of soil separate	*1 mm.*	*1 mm.–⅛″*	⅛″–¼″	¼″–⅜″	⅜″–½″	*unsieved*
Exch. CaO %	0·47	0·43	0·47	0·49	0·50	0·46
Soluble P_2O_5 %*	0·0030	0·0021	0·0031	0·0039	0·0040	0·0032
„ K_2O %*	0·014	0·015	0·017	0·018	0·020	0·015
Moisture %	1·6	1·6	1·5	1·6	1·4	1·5
Loss on ignition %	12·3	11·3	12·4	12·9	12·6	11·5
Coarse sand %	16·2	25·0	18·5	20·2	20·3	20·2
Fine sand %	13·2	10·8	13·6	11·5	11·3	13·2
Silt %	30·6	29·2	29·0	27·5	27·0	25·8
Clay %	28·1	22·5	25·7	25·2	26·2	28·2
Sesquioxides %	2·3	2·2	2·3	2·5	2·3	2·4
pH	7·04	6·44	6·43	6·47	6·48	6·39

* Soluble in N/2 acetic acid.

The lime status and pH of this soil were high and have remained at a high level as shown by subsequent check analyses. The phosphate status was low, a normal condition in the area, while potash was of medium status. While there is some suggestion that the sieving process shifted the distribution of nutrients slightly in favour of the coarser separates this effect was small and is difficult to reconcile with the mechanical analysis where, as expected, the finest separate contained a somewhat higher proportion of clay than the coarse separates. The mechanical analysis shows the soil to be a loam. The effect of the sieving process was most marked in the separate 1 mm.–⅛ in. where the increase in the proportion of coarse sand was noteworthy. It does not appear, however, that either the mechanical or chemical composition of the soils, as analysed, was greatly changed by the sieving process. These figures, being based on the usual fine-earth fraction (< 2 mm.), do not, however, take account of the larger proportion of stones in the coarser separates and in the unsieved soil when compared with the fine separates. As a percentage of oven-dried soil by weight these amounted to approximately 25, 18, 12, 2 per cent. and none, in the separates (from coarsest to finest), while unsieved soil contained approximately 16 per cent. Thus it has to be recognized throughout that the seed-beds differed not only in the aggregate-size of the separate but also in the degree of stoniness. Short of hand-sorting the stones, which is impracticable, this disadvantage is inherent in the sieving technique in this soil.

Daily counts were taken of the emergence of the coleoptiles in the centre four rows of each plot. The data for mean day of emergence and percentage emergence derived from these counts are given below.

Mean day of emergence. The analyses of variance of these data for the spring and autumn experiments 1954–6 are summarized in Table 8.

The salient points which emerge from this summary are:

That, as might be expected, the length of the interval between sowing and emergence was consistently and highly significantly affected by the date of sowing.

TABLE 8. *Mean Day of Emergence—Summary of Analyses of Variance 1954–6*

Component	D.F. 1954 1955	1954 Variance	1954 F Value	1955 Variance	1955 F Value	1956 D.F.	1956 Variance	1956 F Value
Spring barley								
Time of sowing	2	140·98	183·1†	716·61	1592·4†	2	114·52	327·1†
Replicates	1	1·84	n.s.	0·47	n.s.	1	1·93	n.s.
Error (*a*)	2	0·77	..	0·45	..	2	0·35	..
Soil-separate aggregate-size	5	4·53	34·8†	5·16	39·6†	5	1·60	3·76*
Consolidation	1	0·42	n.s.	0·00	n.s.	..	..	..
Soil/consol.	5	0·31	n.s.	0·04	n.s	..	..	..
Time/soil	10	0·26	n.s.	0·16	n.s.	10	0·49	n.s.
Time/consol.	2	0·36	n.s.	0·18	n.s.	..	..	..
Time/soil/consol.	10	0·19	n.s.	0·13	n.s.	..	..	..
Error (*b*)	33	0·13	..	0·13	..	15	0·42	..
Winter oats								
Time of sowing	2	269·18	708·40†	918·43	4353·8†			
Replicates	1	0·07	n.s.	3·30	n.s.			
Error (*a*)	2	0·38	..	0·21	..			
Soil-sep. aggregate-size	5	5·80	36·82†	2·86	29·17†			
Consolidation	1	0·97	6·14*	0·80	8·20*			
Soil/consol.	5	0·17	n.s.	0·04	n.s.			
Time/soil	10	0·35	2·22*	0·06	n.s.			
Time/consol.	2	0·06	n.s.	0·08	n.s.			
Time/soil/consol.	10	0·30	n.s.	0·09	n.s.			
Error (*b*)	33	0·157	..	0·098	..			

† Significant at P = 0·01. * Significant at P = 0·05. n.s. = not significant.

The 'soil-separate aggregate-size' treatment had a significant or highly significant effect on the mean day of emergence in all the experiments.

Consolidation treatments affected the autumn-sown plots but not the spring-sown ones in so far as this factor was concerned.

The time-of-sowing/soil-separate-aggregate-size interaction reached a significant level once—in autumn 1954, and then by a narrow margin.

The differences in M.D.E. attributable to the 'time-of-sowing' treatment are so great that it has not been considered necessary to tabulate the means with their appropriate significant differences. The mean values are shown diagrammatically in Fig. 3 where the close connexion between sowing–emergence interval and the mean soil temperature is clearly demonstrated. Barnard [14] has shown that under British conditions this interval is dependent on the mean soil temperature, neither rainfall nor variation in temperature having any appreciable effect. Under conditions of extreme drought, however, emergence may be slow and erratic [15]. Tables 9 and 10 give the mean plot values relevant to the soil and consolidation treatments shown to be significant in Table 8.

The 'Mean Day of Emergence' was consistently affected by the aggregate-size of the separates which made up the seed-beds. The peak of emergence was earlier in fine plots and later in coarse ones. Unsieved soil occupied an intermediate position in all experiments.

In both the experiments on winter oats emergence was earlier on

TABLE 9. *The Effect of Soil-Separate Aggregate-Size on the Mean Day of Emergence (Means of twelve plots (six plots 1956))*

Soil-separate aggregate-size	1 mm.	1 mm.–$\frac{1}{8}$″	$\frac{1}{8}$″–$\frac{1}{4}$″	$\frac{1}{4}$″–$\frac{3}{8}$″	$\frac{3}{8}$″–$\frac{1}{2}$″	unsieved	L.S.D.	
	Mean day of emergence						P = 0·01	P = 0·05
Spring barley 1954	14·24	14·31	14·71	15·10	15·66	15·58	0·38	0·29
,, ,, 1955	15·16	15·57	15·82	16·32	16·94	16·52	0·38	0·29
,, ,, 1956	16·06	16·23	15·74	16·32	17·22	15·96	..	0·80
Winter oats 1954	14·98	15·72	16·26	16·58	16·97	16·09	0·42	0·32
,, ,, 1955	19·11	19·70	19·89	20·14	20·54	20·13	0·33	0·25

TABLE 10. *The Effect of Consolidation on Mean Day of Emergence (Means of thirty-six plots)*

	Mean day of emergence		L.S.D.	
	Not Consolidated	Consolidated	P = 0·01	P = 0·05
Winter oats 1954 .	16·22	15·98	..	0·187
,, ,, 1955 .	20·02	19·81	0·190	..

consolidated plots and later on unconsolidated plots; the difference though significant was small, less than half a day. Table 14 shows, however, that the total number of coleoptiles which finally emerged was higher on the unconsolidated plots.

It may be argued that the quicker emergence of the oat coleoptiles on consolidated plots resulted from the fact that, although the seeds were covered by the same weight of soil in consolidated and unconsolidated plots, in the former the depth of sowing was slightly reduced by compression. If this were the complete explanation, however, one would have expected the spring barley to exhibit the same trend, which it did not. It would appear that consolidation of the seed-bed has some additional effect on the emergence speed of winter oats.

The significant interaction between time of sowing and aggregate-size of soil separate which was apparent only in autumn 1954 is represented graphically in Fig. 4. It would appear to indicate that the difference in sowing–emergence interval between fine and coarse plots was greater in the latest (November) sowing than in the earlier ones.

Percentage emergence. A summary of the analyses of variance of these data (transformed to degrees) is presented in Table 11 while the mean values for different sowing dates on the various soil treatments are represented diagrammatically on Fig. 3.

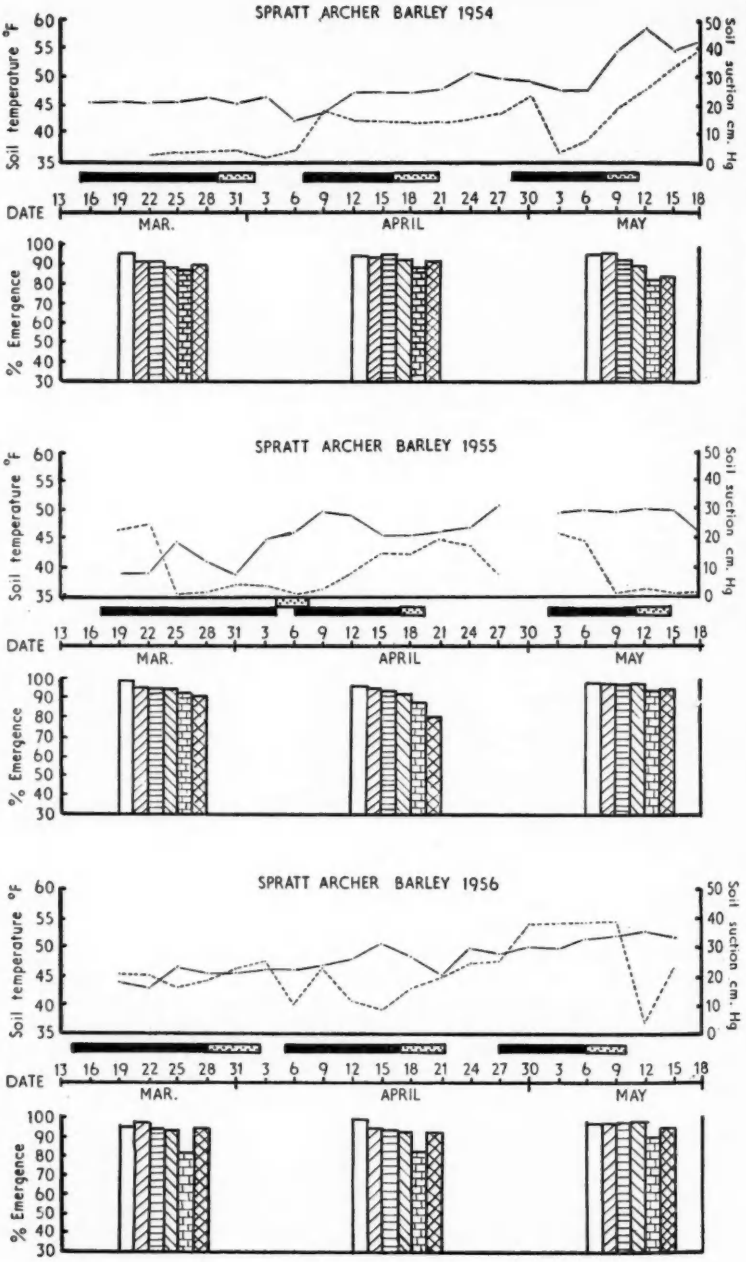
The summary shows that:

Time of sowing had a significant effect on percentage emergence only in spring 1955 and in autumn 1954.

Soil-separate aggregate-size had a highly significant effect on percentage emergence in all the experiments.

Consolidation did not appear to influence percentage emergence to any marked extent, reaching significance in the autumn of 1955 only.

The interaction between 'time of sowing' and 'soil-separate aggregate-


SPRATT ARCHER BARLEY 1954
Soil temperature °F
60
55
50
45
40
35
Soil suction cm. Hg
50
40
30
20
10
0
DATE
13 16 19 22 25 28 31 3 6 9 12 15 18 21 24 27 30 3 6 9 12 15 18
MAR.
APRIL
MAY
% Emergence
100
90
80
70
60
50
40
30
SPRATT ARCHER BARLEY 1955
Soil temperature °F
60
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Soil suction cm. Hg
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SPRATT ARCHER BARLEY 1956
Soil temperature °F
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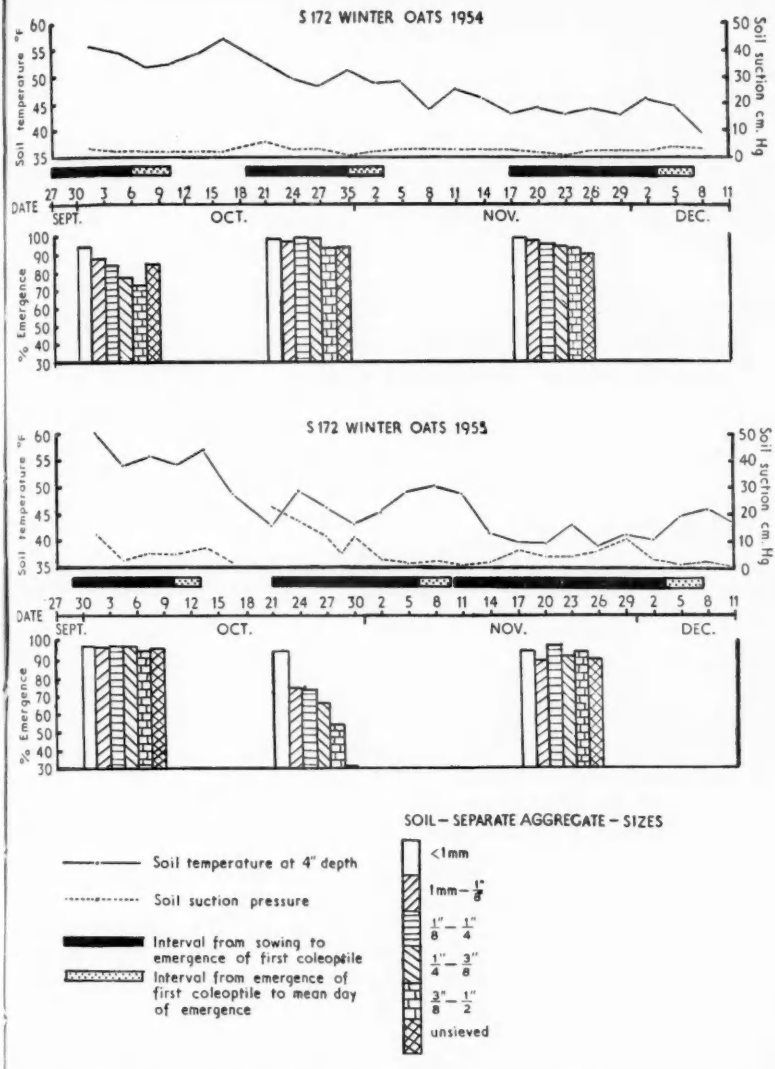

FIG. 3. Diagrammatic summary of experimental results 1954–56 showing soil temperatures and suction pressures, dates of sowing and emergence, mean day of emergence and percentage emergence.

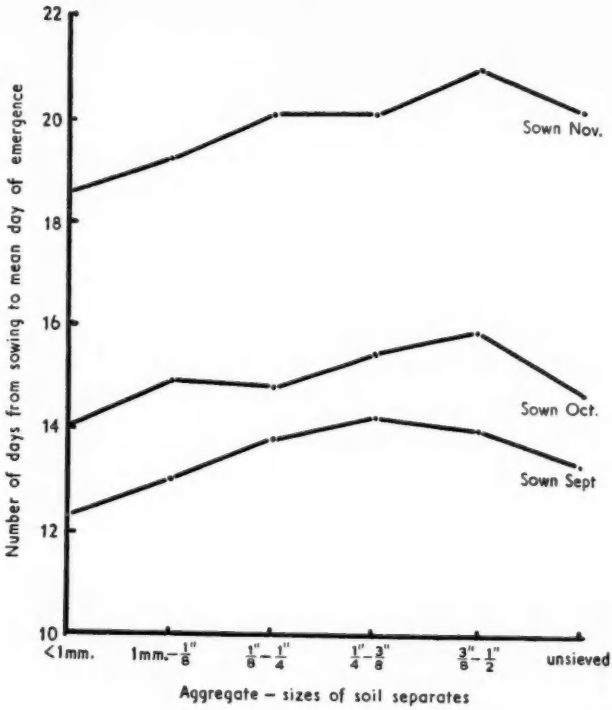

FIG. 4. Autumn 1954. S.172 winter oats—mean-day-of-emergence interaction between aggregate size of soil separate and time of sowing. (Each point is a mean of 4 plots.)

size' treatments reached significant levels in the autumn experiments but not in the spring ones.

The second-order interaction (time of sowing/soil/consolidation) just reached a significant level in the autumn 1954 experiment.

Tables 12, 13, and 14 show the means relating to these treatments and the least significant differences between means. Both the means of the original percentages and of the transformed data are presented; the L.S.D. figures relate to the latter only.

Reference to Fig. 3 and to Tables 11 and 12 shows that there was no consistent trend in favour of any particular time of sowing as the optimum for high-percentage emergence; this is true for both spring and autumn experiments. The work has not, in any case, extended over a sufficient number of seasons for any generalizations of this kind to be permissible. In the autumn 1955 results (see Fig. 3) the differences between 'time-of-sowing' treatments did not reach significant levels (despite the obvious inferiority of the October sowing) because of the

TABLE 11. *Coleoptiles Emerged per 100 Seeds Sown (Percentages transformed to Degrees)*

Component	D.F. 1954 1955	1954 Variance	1954 F Value	1955 Variance	1955 F Value	1956 D.F.	1956 Variance	1956 F Value
Spring barley								
Time of sowing	2	45·6	n.s.	350·8	1002·4†	2	88·2	n.s.
Replicates	1	15·6	n.s.	10·7	30·6*	1	..	..
Error (*a*)	2	14·5	..	0·35	..	2	18·0	..
Soil-separate aggregate-size	5	139·4	9·1†	165·2	15·8†	5	144·9	5·12†
Consolidation	1	5·0	n.s.	5·5	n.s.	..	..	..
Soil/consol.	5	5·2	n.s.	11·8	n.s.	..	..	..
Time/soil	10	25·8	n.s.	21·4	n.s.	10	10·8	n.s.
Time/consol.	2	7·8	n.s.	11·5	n.s.	..	..	..
Time/soil/consol.	10	13·1	n.s.	8·7	n.s.	..	..	..
Error (*b*)	33	15·3	..	10·5	..	15	28·3	..
Winter oats								
Time of sowing	2	1337·4	49·5*	4274·7	n.s.			
Replicates	1	4·0	n.s.	185·0	n.s.			
Error (*a*)	2	27·0	..	310·5	..			
Soil-separate aggregate-size	5	281·1	14·3†	364·3	16·9†			
Consolidation	1	15·1	n.s.	92·5	4·3*			
Soil/consol.	5	14·8	n.s.	32·0	n.s.			
Time/soil	10	54·9	2·8*	251·9	11·7†			
Time/consol.	2	34·2	n.s.	6·3	n.s.			
Time/soil/consol.	10	46·3	2·36*	11·5	n.s.			
Error (*b*)	33	19·6	..	21·5	..			

† Significant at P = 0·01. * Significant at P = 0·05. n.s. = not significant.

TABLE 12. *The Effect of Sowing Date on Percentage Emergence (Means of twenty-four plots)*

Time of sowing	Early	Medium	Late	L.S.D. 0·01	L.S.D. 0·05
Spring barley 1955					
Percentage emergence	94·6	91·7	97·5	..	..
Degrees	77·1	74·2	81·8	2·39	..
Winter oats 1954					
Percentage emergence	83·9	96·7	94·7	..	..
Degrees	67·3	81·6	78·1	..	6·45

larger error variation. The time-of-sowing/soil-separate aggregate-size interaction was, however, significant. From Fig. 3 it would seem that, in these experiments, no obvious relationship exists between the percentage emergence and the soil temperature or the soil suction pressure. It may be noted, nevertheless, that among the autumn sowings the October 1955 seed-beds, which gave a very poor emergence on all but the finest plots, were particularly dry during most of the pre-emergence period. Dryness of the seed-bed did not appear to have any effect on the percentage emergence of spring barley.

TABLE 13. *The Effect of Soil-Separate Aggregate-Size on Percentage Emergence (Means of 12 plots)*

Soil-separate aggregate-size	*1 mm.*	*1 mm.–⅛″*	*⅛″–¼″*	*¼″–⅜″*	*⅜″–½″*	*unsieved*	*L.S.D.* P = 0·01	*L.S.D.* P = 0·05
Spring barley 1954								
Percentage emergence .	94·7	93·7	92·7	90·5	86·2	88·4		
Degrees .	77·2	75·8	74·8	72·4	68·3	70·4	4·16	3·20
Spring barley 1955								
Percentage emergence .	97·8	96·7	95·9	95·2	92·3	89·6		
Degrees .	82·2	80·6	78·6	78·0	74·5	72·3	3·43	2·64
Spring barley 1956								
Percentage emergence .	96·6	96·5	95·3	94·5	84·3	93·5		
Degrees .	80·7	79·8	77·9	77·8	67·2	75·6	8·53	6·54
Winter oats 1954								
Percentage emergence .	97·6	94·6	92·7	90·5	86·2	89·2		
Degrees .	82·8	78·1	77·4	75·1	69·6	71·2	4·71	3·62
Winter oats 1955								
Percentage emergence .	94·8	86·5	88·9	84·9	80·5	72·2		
Degrees .	77·5	70·3	73·5	70·0	66·4	61·6	4·91	3·78

From this table it may be concluded that, under the experimental conditions described, fine seed-beds gave a higher percentage emergence than coarse ones. Unsieved soil usually occupied an intermediate position but gave poor performances in spring 1955 and, particularly in autumn 1955, when, as a result of dry weather, the natural unsieved soil contained a high proportion of large stable clods. As a consequence these unsieved seed-beds were coarser than usual.

TABLE 14. *The Effect of Seed-bed Consolidation on Percentage Emergence, Winter Oats 1955 (Means of 36 plots)*

Consolidation	*Not consolidated*	*Consolidated*	*L.S.D.* P = 0·05
Percentage emergence	86·0	83·3	..
Degrees . .	71·0	68·7	2·18

The autumn 1955 experiment was the only one in which the consolidation treatment had any significant effect on the percentage emergence. Here the figures indicate that unconsolidated seed-beds had a significantly higher percentage emergence than consolidated seed-beds. Some additional weight is given to this observation by the fact that the trend in autumn 1954, though not reaching significance, was also in favour of the loose seed-beds.

The significant interactions between time of sowing and soil-separate aggregate-sizes are illustrated diagrammatically on Fig. 3. The most probable interpretation of these data would appear to be that, when environmental conditions are unfavourable for emergence, coarse plots are more adversely affected than fine ones. When conditions are favourable the differences between coarse and fine seed-beds are minimized.

Conclusions and Discussion

The most obvious conclusion to be drawn from these experimental results is that, on this soil under the conditions described, all grades of seed-bed carried, as a general rule, ample plants to produce a crop. That is, the cereals used were able to germinate and emerge on seed-beds ranging from fine ones consisting of aggregates below 1 mm. in diameter to those consisting very largely of clods and stones between $\frac{3}{8}$ and $\frac{1}{2}$ in. diameter. So far, therefore, the conclusions of the Rothamsted workers [1, 3, 4, 5] that cereals are comparatively insensitive to wide differences in tilth are borne out. Nevertheless, the finest seed-beds usually had an advantage over the coarsest of about 10 per cent. in emergence percentage. The difference was much greater at certain times but the particular combination of environmental factors which accentuated the difference between emergence on fine and coarse plots could not be determined. The mean day of emergence was invariably earlier on fine seed-beds than on coarse ones. The differences between plant populations on the finer as opposed to the coarser seed-beds were more marked in the pilot experiment of 1951 than in any subsequent experiment on barley. An observation was made at that time which may, to some extent, account for this. The plots were in a garden which had a very high population of the small slug *Limax carinatus*. These certainly attacked the plants above-ground and it is equally certain that, whereas many were sheltering in the interstices of the coarse seed-beds, none could shelter in the fine ones which had a smooth compact surface. It appeared, from examination of uprooted seeds which had failed to emerge, that the failure to emerge in coarse plots was caused (to some degree) by the subterranean destruction of the coleoptiles by these slugs. It is possible that this observation on pest/tilth relationship may have some relevance to certain pest attacks under field conditions. The influence of consolidation, as applied in these experiments, was small. There is some evidence that winter oats were more responsive to changes in the firmness of the seed-bed than was spring barley. In no instance was the percentage emergence or mean day of emergence of the latter affected significantly, whereas winter oats had an earlier M.D.E. in consolidated plots in both 1954 and 1955. In the former year the total number of winter-oat emergences was significantly reduced by consolidation. This soil did not form hard surface crusts even on the finest seed-beds. After heavy rain a crust did form on both the 1 mm. and 1 mm.–$\frac{1}{8}$ in. sizes but the coleoptiles evidently had no difficulty in penetrating it even when it had dried. Usually a small angular piece of crust was lifted by the emerging coleoptile; this is illustrated in

(Fig. 5, Plate 1). Coleoptiles in the coarsest seed-beds often emerged at an angle, which points to mechanical impedence as the factor responsible for their slower emergence. The conditions here described bear no apparent relationship to those described by either DeMent [11] or Kodama and Suzuki [12] where hard surface crusts were an important factor inhibiting emergence. The absence of puddling and waterlogging in the finest seed-beds and the stability of the aggregates of all sizes under field conditions was remarkable. Certain physical data on this soil will be presented in later papers as will the data referring to the post-emergence development and survival of the plants.

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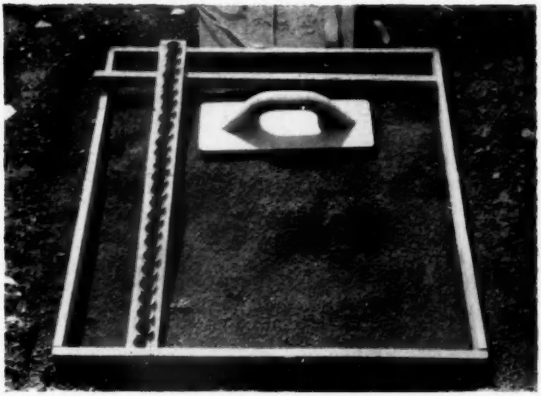

FIG. 1. Equipment used for sowing assembled for display—not in working positions

FIG. 2. Sowing frame and straight edge—illustrating method of achieving constant sowing depth

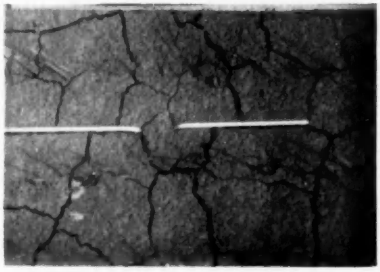

FIG. 5. Crusting on the finest plot (< 1 mm.) showing seedlings emerging and soil thermometers in position

END-OF-SEASON DESTRUCTION OF COTTON PLANTS IN THE SUDAN GEZIRA

S. A. J. TARR

(*Chief Plant Pathologist, Research Division, Ministry of Agriculture, Sudan*)

Summary

The various factors affecting regrowth ('ratoons') of cotton plants in the Sudan Gezira following end-of-season cutting at soil level in April-May are described. Magnitude and distribution of rainfall are important factors, e.g. light early rains in June-July tend to delay regrowth, and heavy insect infestation (flea-beetle) can reduce the incidence of green leafy ratoons in July-August. Cutting in late May and June resulted in later regrowth than cutting in April and early May. Even with favourable rain there was usually relatively little regrowth until a month or so after cutting, perhaps suggesting a 'dormancy period' in such cut stumps. Heavy early rain in July and early August did not necessarily stimulate immediate regrowth of all living stumps in the soil, considerable numbers sprouting in September and, to a lesser extent, in October.

Cutting the tap roots 6 inches below soil level greatly reduced and delayed subsequent regrowth of the remaining stumps, but in some seasons deeper cutting would probably be necessary to ensure the high degree of control usually obtained with efficient hand pulling as practised in the Gezira. The most effective chemical control method was by immediate wetting of cut stumps with 5 per cent. 2,4-D amine solution in water, using about 0·5–1 c.c. per stump (2·2–4·4 galls./acre). With this method 2,4-D (sodium salt) was slightly and 2,4-D ester markedly less effective than 2,4-D amine. In these experiments the MCPA, MCPB, and 2,4,5-T compounds tested gave poorer control than 2,4-D compounds although 2,4,5-T gave good results in some trials; 5 per cent. sodium chlorate solution and 10, 30, 50, and 70 per cent. ammonium sulphamate solutions gave only slight control.

In the Sudan Gezira control of leaf-curl disease of Egyptian-type cotton, *Gossypium barbadense* L., caused by the cotton-leaf-curl virus (Gossypium virus 1) is largely by destruction of the cotton plants at the end of the season, thereby minimizing seasonal carry-over of the virus in living plants which resume growth ('ratoons') during the following rainy months. Cultivation of alternative hosts of the disease, certain Malvaceae and especially *Hibiscus* spp., between successive cotton crops, is prohibited by law. The virus does not persist in dead plant trash or soil, is not seed-borne, and in the field is spread by the cotton whitefly *Bemisia tabaci* Genn. (*B. gossypiperda* M. & L.). Only certain species of the family Malvaceae are known to be susceptible, as discussed elsewhere [1].

Leaf curl can cause heavy crop losses to the Sakellarides ('Sakel') variety of Egyptian cotton in the Gezira and it is of great practical importance to reduce ratoon growth to a minimum. At present the plants are pulled out, using a heavy hand-operated iron puller which works on the pincer-and-lever principle and removes much of the tap-root and some of the larger lateral roots from the soil. Although very effective if carefully carried out this method suffers certain disadvantages. Some roots break during pulling and often survive to produce regrowth a few months

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later, and the task of pulling out some 20,000 cotton plants per acre over nearly a quarter of a million acres is a laborious and expensive one. When mature the plants are woody, up to about 5 feet in height and have stems up to an inch or more in diameter at soil level. Sakel cotton is essentially a perennial plant and if cut out at ground level it produces profuse ratoon growth when rain falls a few months later. In the Gezira pulling-out is carried out in April-May; a small and varying amount of rain (average 30 mm.) falls in June and may result in a few ratoons but usually many more come up in the wetter months of July (130 mm.) and especially in August (130 mm.) and September (50 mm.). Rainfall in the Gezira shows considerable variation between long-term annual averages of 200–300 mm. (minimum 150 mm.) in the north and 400–500 mm. (maximum 650 mm.) in the south. June rainfall varies between nil and nearly 100 mm. Cotton is sown in mid-August and becomes infected with leaf curl by whitefly migrating from infected ratoons. The crop is never sown in the same field in two consecutive seasons, there being a three- or four-year rotation throughout the Gezira. Methods of destroying cotton plants which are less laborious than hand-pulling and equally effective are needed, and mechanized pullers are being designed. The investigation described below included a study of regrowth in relation to rainfall and date of cutting, and control of regrowth by mechanical and chemical methods. Except where stated otherwise all plot experiments took the form of randomized blocks with five to nine replicates and were carried out at the Gezira Research Farm, Wad Medani, during the years 1951–6. To avoid the danger of spreading leaf curl, the leaf-curl-resistant X1730A variety of *Gossypium barbadense* was used throughout; this variety is similar to Sakel and was in fact originally selected from a field of Sakel cotton in the Gezira.

Regrowth in Relation to Rainfall and Date of Cutting

In Table 1 are summarized data for cumulative seasonal rainfall, and regrowth after cutting cotton plants at ground-level on the dates specified. Regrowth is expressed as a percentage of the final total re-

TABLE 1. *Regrowth, expressed as Percentage of Final Regrowth, and Cumulative Rainfall in mm.*

Date of observation	*1951*		*1953*			*1955*			*1956*	
		Cut		*Cut*			*Cut*			*Cut*
	Rain	*5 May*	*Rain*	*15 Apr.*	*15 May*	*Rain*	*15 Apr.*	*15 May*	*Rain*	*1 May*
mid-June	23	4·8	63	44·4	14·1	57	7·4	1·8	7	1·5
1 July	26	10·7	91	78·6	20·7	86	23·6	3·8	38	6·3
mid-July	35	24·8	128	94·9	49·2	103	68·9	32·3	101	16·0
1 August	55	29·4	176	95·5	64·7	164	77·7	42·1	159	36·2
mid-August	74	39·2	321	96·0	75·5	229	82·2	51·0	290	64·2
1 September	181	66·2	335	99·0	91·4	237	86·7	66·1	319	97·4
mid-September	190	84·1	358	100	98·5	296	96·4	92·2	418	99·3
1 October	218	90·4	361	100	99·8	310	99·7	98·2	423	99·5
mid-October	231	100	363	100	100	320	100	100	439	100
Final % regrowth		50·3		62·8	54·7		30·8	44·9		54·0

growth in mid-October, after which date virtually no further sprouting occurred. The bottom row gives the actual percentage of stumps which had sprouted by mid-October.

Regrowth was relatively slight in June-July 1951, probably because the early rains were abnormally low (74 mm. up to mid-August as compared with long-term average of some 270 mm.); with heavier rain in the second half of August regrowth increased and attained its maximum rate. In 1953 and 1955 early rain was much heavier and plants cut in mid-April showed maximum regrowth in June-July, particularly in 1953 when regrowth was very early, perhaps because the plants were robust and gave a high final percentage regrowth (63) as compared with only 31 in 1955. Cutting in May appreciably delayed sprouting, maximum regrowth occurring in July-August. June rainfall was light in 1956 and no considerable regrowth developed until late July and (particularly) August.

These examples indicate that distribution and magnitude of rain have a marked influence on regrowth, e.g. very light early rains, as in 1951, will tend to result in late appearance of ratoons. These are aspects of considerable practical significance since ratoon cotton is supposed to be destroyed whenever it appears, and at certain times, e.g. at about sowing time, the cultivator may be too preoccupied to deal with it—thereby permitting ratoons to survive sufficiently long to become sources of leaf-curl infection for the newly sown fields.

Ratoon cotton is often attacked by insects, notably by flea-beetles (*Podagrica puncticollis* Weiss.), in July-August and in some seasons infestation may cause death of the young leaves and sometimes of the whole stump. For this reason the number of ratoons with green leafy growth, excluding those which had sprouted and apparently died, was recorded at 2-weekly intervals after cutting plants at ground level (0 in.), or at 3 in. and 6 in. below ground level, at five dates in April-June 1954 (Table 2). The percentages given refer to ratoons with living green leaves at the time of inspection. No regrowth occurred after cutting at 6 in.

TABLE 2. *Percentage of Stumps with Green Leafy Growth*

Date of observation	Date and depth of cutting									
	mid-April		*1 May*		*mid-May*		*1 June*		*mid-June*	
	0″	3″	0″	3″	0″	3″	0″	3″	0″	3″
mid-June	1·4	0·1	0·6	..	7·8	..	6·4	..	..	..
1 July	3·0	0·1	0·6	..	8·9	..	9·4	0·1	6·6	..
mid-July	2·3	0·0	0·6	..	10·7	..	12·6	0·0	13·8	..
1 August	3·0	0·1	1·6	..	10·0	..	10·9	0·0	13·3	..
mid-August	3·3	0·0	1·7	..	9·9	..	13·4	0·0	14·4	..
1 September	2·2	0·7	2·8	0·1	11·8	0·1	14·8	0·8	21·7	0·4
mid-September	1·7	0·3	2·9	0·0	14·9	0·0	21·3	0·6	32·1	0·7
1 October	1·7	0·3	3·3	0·0	16·2	0·0	22·7	0·6	34·1	0·8
Average	2·3	0·2	1·8	0·01	11·3	0·01	13·9	0·3	19·4	0·2

Plants cut at ground level in mid-April and early-May showed regrowth largely in the second half of June, July, and the first half of

August. This regrowth was largely eaten off by insects, there being no sown cotton at that time and flea-beetles being very prevalent in July and early August, and the incidence of green sprouting ratoons thus remained at a very low level. Regrowth of later-cut plants occurred somewhat later and so tended to survive these insect depredations, such stumps showing a fairly low and uniform level of ratoon growth in July and early August when flea-beetle attack was at its height and a marked increase after the middle of August when insect infestation declined. Cutting at 3 in. below ground level greatly reduced subsequent regrowth and none occurred with plants cut at 6 in. Plants left *in situ* in the soil (not cut) showed an average of 73·4 per cent. survival in mid-July. These figures should be compared with those in Table 3 in which are summarized cumulative percentages of sprouting plants, as opposed to incidence of green ratoons, following cutting at the same five dates in 1955. In the field insect attack and grazing by stock can appreciably reduce ratoon growth although these are not controlling factors to be relied upon every season. With plants cut on 1 May 1956 flea-beetle infestation of leafy ratoons commenced in early July, reached its peak in mid-July and thereafter gradually declined to become relatively slight by mid-August. This cycle was reflected in counts of percentage ratoons with green leafy growth: 79 on 7th, 29 on 14th, 55 on 21st, 59 on 28th July, 71 on 11th, 91 on 25th August, 90 on 15th, 87 on 29th September, and 76 on 13th October when the ratoons began to wither from lack of water. Flea-beetles caused rapid death of ratoon leaves but many stumps survived and produced new shoots when insect infestation declined.

From these and other experiments it became evident that flea-beetles, although not preventing regrowth, could attack leafy ratoons and so reduce their incidence. This was particularly so in July and early August but was of little account in September; no doubt it is a seasonal effect determined by climatic and other factors. Under field conditions cotton regrowth would also be grazed by stock to varying extents. In addition to the factors discussed above (amount and distribution of rain, date and depth of cutting, insect infestation) incidence of regrowth is also influenced by other factors such as size and vigour of the roots remaining in the soil, soil conditions, and the weather prevailing during the dry months between successive cotton crops. Thus in one experiment stumps of a poor crop with small plants gave only 8·7 per cent. regrowth, whereas roots from large plants of a good crop invariably produced 30–60 per cent. regrowth. Prolonged very hot dry weather between crops probably reduces the survival of roots in the soil as suggested by experiments [2] in which regrowth was reduced by lengthening the dry intercrop period (by early termination of irrigation) and increased by shortening it (by extending irrigation until mid-April). Early stoppage of irrigation in mid-March followed by cutting at ground level in mid-May also reduced regrowth [3].

Control by Mechanical Methods

Ploughing the cotton fields with 6 in. and 12 in. disks and with a Prairie Disk Tiller gave inadequate control of subsequent regrowth

although the plants were dislodged, often buried and sometimes killed. Often, however, buried plants survived to produce extensive ratoon growth from numerous buds along the stems. This regrowth was often much greater in quantity per plant than that produced by normal stump ratoons resulting from imperfect pulling. Since the aerial parts of the plant have to be burnt at the end of the season to prevent carry-over of blackarm disease (*Xanthomonas malvacearum*) further investigation was concentrated on cutting the plants at several depths below soil level.

Table 3 summarizes the cumulative percentages of regrowth of plants cut at ground level (0 in.), 3 in. and 6 in. depth on five dates in April-June 1955.

TABLE 3. *Percentage Regrowth (cumulative)*

Date of observation	*Date and depth of cutting*														
	mid-April			*1 May*			*mid-May*			*1 June*			*mid-June*		
	0″	3″	6″	0″	3″	6″	0″	3″	6″	0″	3″	6″	0″	3″	6″
mid-June	1·5	..	..	1·4	..	..	0·7	..	..	0·1	..	..	..	..	..
1 July	4·0	..	..	5·4	..	..	1·0	..	..	0·2	..	..	..	..	..
mid-July	17·0	4·8	..	20·5	1·3	..	12·9	2·4	..	8·4	..	..	1·8	..	..
1 August	19·6	5·7	..	25·6	1·5	..	17·6	3·6	..	13·1	..	..	3·9	..	..
mid-August	20·8	5·8	..	25·9	1·5	..	21·4	3·7	..	18·6	..	..	7·3	..	..
1 September	22·4	5·9	..	30·3	1·6	0·1	30·0	4·6	..	25·9	0·2	..	17·5	0·1	0·1
mid-September	25·4	7·5	0·1	37·3	3·3	0·1	43·7	9·0	0·1	39·7	1·6	0·1	34·6	2·9	0·1
1 October	26·5	7·9	0·1	39·0	5·6	0·4	47·7	11·4	0·6	43·2	3·7	0·3	38·3	6·6	0·2
mid-October	26·7	8·1	0·1	39·5	6·5	0·4	48·7	12·8	0·6	44·5	4·5	0·3	39·4	7·5	0·3
1 November	26·7	8·3	0·1	39·7	6·6	0·4	49·0	12·9	0·7	44·7	4·6	0·3	39·7	7·5	0·3
mid-November	26·8	8·4	0·1	39·7	6·7	0·4	49·0	13·2	0·9	44·8	4·8	0·3	39·8	7·8	0·3

Cutting at 3 in. below soil level reduced total subsequent regrowth to about 5–13 per cent. as compared with some 27–49 per cent. for cutting at ground level and also delayed the appearance of regrowth by about a month. Cutting at 6 in. depth was more effective, reducing total subsequent regrowth to less than 1 per cent. and delaying its appearance until late August or early September. In a further trial with cutting at 6 in. above ground level, at ground level, and at 3, 6, and 9 in. below ground level, on 1 May 1956, no regrowth occurred with the deepest two cuttings and it was evident that the higher the cutting the more profuse and earlier was subsequent regrowth (Table 4).

TABLE 4. *Percentage Regrowth (cumulative) resulting from Various Cutting Depths*

Depth of cutting	*Date of observation*				
	mid-June	*mid-July*	*mid-Aug.*	*mid-Sept.*	*mid-Oct.*
+6 in.	25·3	65·2	69·7	79·2	79·3
0	0·8	8·7	30·0	53·6	54·0
−3 in.	nil	0·1	0·3	1·1	1·27

When a cotton plant is cut through below the cotyledonary node the remaining root may later produce leafy shoots developing from adventitious buds formed on small protruding cushions of soft, white, parenchymatous tissue perhaps originating from modified lenticels [4]. Such

cutting, although not preventing regrowth, delays and reduces it; thus cumulative regrowth of stumps cut on 3 May 1956 was 31 per cent. (cut above the cotyledonary node) and 3 per cent. (cut below node) at the end of June, 37 and 6 per cent. in mid-July, 43 and 24 per cent. in mid-August, and 62 and 52 per cent. in mid-September. The experiments described above show that regrowth can originate from a depth of more than 6 in. and suggest that in field practice a somewhat greater cutting depth than this would be advisable since regrowth as little as 1 per cent. would be too much in the Gezira, where there are more than 20,000 plants per acre.

Cutting in late May and early June invariably resulted in later regrowth than earlier cutting in April and early May. Often no considerable regrowth occurred, despite favourable rain, until a month or more after cutting although a few stumps sprouted in as little as two weeks. Another point of practical importance is that heavy rain in July-August did not stimulate immediate regrowth of all living roots in the soil; considerable regrowth occurred in September and a small amount in October. (In September rainfall is declining and normally October rainfall averages only about 15 mm. at the Gezira Research Farm.) This tendency became more pronounced with later cutting and suggests that cotton stumps often undergo a 'dormancy period' after cutting, during which only slight regrowth occurs even when climatic and soil conditions are very favourable for such regrowth. This is illustrated in Table 1 where despite favourable rain plants cut in mid-May 1955 showed no considerable regrowth until mid-July whereas those cut in mid-April 1953 showed considerable regrowth in June. A similar general tendency is evident in the other data presented in Tables 1 and 3.

Control by Chemical Methods

Application of various chemicals to standing plants or cut stumps at the end of the season (April-May) was investigated.

Spraying standing plants in early May at the rate of 100 gallons/acre of 1 per cent. water solution of various selective weedkillers gave unsatisfactory control, the percentages of regrowth being 82·5 (unsprayed), 82·4, and 75·4 for two formulations of 2-methyl-4-chlorophenoxyacetic acid (sodium salt, hereafter referred to as MCPA) and 53·5 for 2,4-dichlorophenoxyacetic acid (sodium salt, hereafter referred to as 2,4-D). Since the aerial parts of cotton plants in the Gezira have to be removed and burned as a control measure against blackarm disease, spraying of standing plants was not investigated further.

The same spraying treatments were applied in early April to a field in which the cotton plants had just been cut at ground level. Percentages of regrowth up to mid-August were 31·2 (unsprayed), 31·1, and 29·5 for two MCPA formulations and 15·9 for 2,4-D. As in the previous trial 2,4-D appeared to be more effective than MCPA but the degree of control was quite inadequate in both experiments.

Spraying a field of cotton stumps appears to be a wasteful procedure. Most of the spray falls on the soil surface which is very hot and dry in

April-May when this operation would be carried out. It is likely that some of the spray evaporates, some is absorbed by the hot dry soil particles, and some decomposes. Comparatively little of it is likely to reach and be taken in by the rather widely spaced stumps remaining in the soil, especially since the roots of such stumps would probably be dormant and not actively absorbing moisture from the soil at this time of the year. More satisfactory results were obtained by treating cut stumps and in a preliminary trial such treatment reduced percentage regrowth to 2·65 and 2·41 for 1 per cent. 2,4-D and 1 per cent. MCPA respectively, as compared with 37·41 for 5 per cent. sodium chlorate solution and 50·35 for untreated stumps.

Tables 5 and 6 summarize the results of experiments in which cotton plants were cut at ground level in mid-April and mid-May 1953 and the stumps immediately wetted with the chemicals specified, using about 0·5–1 c.c. per stump (2·2–4·4 galls. per acre). In the statistical analysis of these and subsequent results the untreated controls are omitted and the transformation log (percentage regrowth+1) is used to obtain more precise differentiation between treatments; figures thus transformed are given in parentheses.

TABLE 5. *Percentage Regrowth after Stump Treatment in mid-April 1953*

Untreated 64·1

Chemical used	*Concentration*						*Mean*	
	1%		2½%		5%			
2,4-D .	5·3	(0·76)	1·9	(0·36)	1·1	(0·23)	2·8	(0·45)
MCPA .	10·2	(0·92)	5·8	(0·71)	2·2	(0·45)	6·1	(0·69)
2,4,5-T* .	11·2	(1·00)	8·4	(0·77)	4·1	(0·68)	7·9	(0·82)
Mean .	8·9	(0·89)	5·4	(0·61)	2·4	(0·45)		

* 2,4,5-trichlorophenoxyacetic acid esters.

Minimum significant differences (transformed data):

Individual treatments, 0·3 (P = 0·05) and 0·39 (P = 0·01).

Means, 0·176 (P = 0·05) and 0·238 (P = 0·01).

No significant interaction between kind of chemical and concentration.

TABLE 6. *Percentage Regrowth after Stump Treatment in mid-May 1953*

Untreated 54·5

Chemical used	*Concentration*						*Mean*	
	1%		2½%		5%			
2,4-D .	5·1	(0·72)	1·2	(0·19)	0·3	(0·06)	2·2	(0·32)
MCPA .	15·8	(1·25)	4·5	(0·63)	3·0	(0·55)	7·8	(0·81)
2,4,5-T .	7·6	(0·74)	1·0	(0·22)	0·3	(0·08)	3·0	(0·35)
Mean .	9·5	(0·91)	2·3	(0·35)	1·2	(0·23)		

Minimum significant differences (transformed data):

Individual treatments, 0·29 (P = 0·05) and 0·38 (P = 0·01).

Means, 0·17 (P = 0·05) and 0·23 (P = 0·01).

No significant interaction between kind of chemical and concentration.

2,4-D was significantly more effective than MCPA and 2,4,5-T with April treatment but not superior to 2,4,5-T with May treatment. In most cases 1 per cent. solution gave significantly poorer control than 2½ and 5 per cent. solutions whilst the latter tended to be more effective than 2½ per cent. In general 5 per cent. 2,4-D solution gave the most effective control, MCPA was unsatisfactory at both treatment dates, even in 5 per cent. solution, whilst 5 per cent. 2,4,5-T was satisfactory with May treatment but inadequate with April treatment.

In another experiment cotton plants were cut and the stumps treated in mid-May 1954, the levels of green-ratoon growth during June-October being recorded weekly (Table 7). The figures in this table are a measure of the average incidence of green leafy ratoons per treatment throughout this period; for each treatment the percentage of stumps with green leafy regrowth (excluding dead regrowth) was recorded at sixteen weekly observation dates and the total of these was then divided by sixteen to give the percentages recorded in the table. The data were analysed using the same logarithmic transformation as before (see p. 191).

TABLE 7. *Average Percentage Incidence of Green Leafy Ratoons, June–October 1954*

Untreated 30·0

Chemical used	*Concentration*						*Mean*	
	2½%		5%		10%			
MCPA amine	1·7	(0·41)	0·82	(0·24)	0·36	(0·11)	0·95	(0·25)
2,4,5-T esters	3·8	(0·63)	0·53	(0·17)	0·74	(0·24)	1·70	(0·35)
Mixed esters*	1·5	(0·36)	0·23	(0·08)	0·15	(0·05)	0·62	(0·16)
2,4-D ester (1)	1·0	(0·23)	0·53	(0·18)	0·08	(0·03)	0·52	(0·15)
,, (2)	0·8	(0·21)	0·32	(0·11)	0·12	(0·05)	0·41	(0·12)
2,4-D sodium salt	0·4	(0·12)	0·36	(0·13)	0·11	(0·10)	0·27	(0·12)
2,4-D amine	0·3	(0·12)	0·20	(0·07)	0·09	(0·03)	0·21	(0·07)
Mean	1·3	(0·30)	0·43	(0·14)	0·24	(0·09)		

* A mixture of 2,4-D and 2,4,5-T esters.

Minimum significant differences (transformed data):

Individual treatments, 0·16 (P = 0·05) and 0·21 (P = 0·01).

Chemical means, 0·09 (P = 0·05) and 0·12 (P = 0·01).

Concentration means, 0·06 (P = 0·05) and 0·08 (P = 0·01).

2,4-D compounds were more effective than 2,4,5-T and MCPA amine. 2½ per cent. 2,4-D sodium salt and 2½ and 5 per cent. 2,4-D amine appeared to be more effective than the two 2,4-D ester formulations at equivalent concentrations. In general 2½ per cent. concentration was less effective than 5 and 10 per cent. especially with 2,4,5-T, MCPA-amine, and the mixed-esters formulations. Ten per cent. tended to be more effective than 5 per cent. but not significantly so.

2,4-D compounds and ammonium sulphamate solutions in water (10, 30, 50, and 70 per cent.) were tested in mid-April and mid-May 1955 (Tables 8 and 9); only three replicates of each treatment were possible, resulting in less precise differentiation than in previous trials. There were no significant differences between the control (untreated) and ammonium sulphamate treatments; the significant differences quoted below refer only to the data from the 2,4-D treatments, logarithmically transformed as before (see p. 191). In neither trial was there any significant interaction between kind of chemical and concentration.

TABLE 8. *Percentage Regrowth after Stump Treatment in April 1955*

Untreated 34·9 per cent.

Amm. sulphamate: 10% = 42·1%; 30% = 38·1%; 50% = 29·6%; 70% = 25·6%.

2,4-D compound	*Concentration*						*Mean*	
	2½%		5%		10%			
Ester	1·8	(0·44)	1·5	(0·40)	1·8	(0·44)	1·7	(0·43)
Sodium salt	1·6	(0·37)	1·2	(0·31)	0·3	(0·10)	1·0	(0·26)
Amine (1)	0·8	(0·25)	0·2	(0·07)	0·9	(0·24)	0·6	(0·18)
„ (2)	1·9	(0·44)	0·1	(0·04)	0·6	(0·18)	0·8	(0·22)
Mean	1·5	(0·37)	0·8	(0·20)	0·9	(0·24)		

Minimum significant differences (transformed data):

All treatments 0·26 (P = 0·05), 0·35 (P = 0·01).
Chemical means 0·15 (P = 0·05), 0·21 (P = 0·01).
Concentration means 0·13 (P = 0·05), 0·18 (P = 0·1).

TABLE 9. *Percentage Regrowth after Stump Treatment in May 1955*

Untreated 41·2 per cent.

Amm. sulphamate: 10% = 37·4%; 30% = 43·6%; 50% = 29·0%; 70% = 33·3%.

2,4-D compound	*Concentration*						*Mean*	
	2½%		5%		10%			
Ester	4·3	(0·72)	5·4	(0·72)	3·3	(0·49)	4·3	(0·64)
Sodium salt	1·6	(0·35)	0·3	(0·12)	0·3	(0·11)	0·7	(0·19)
Amine (1)	0·6	(0·19)	0·3	(0·10)	0·7	(0·20)	0·5	(0·16)
„ (2)	0·6	(0·19)	0·3	(0·10)	0·3	(0·09)	0·4	(0·13)
Mean	1·8	(0·36)	1·6	(0·26)	1·1	(0·22)		

Minimum significant differences (transformed data):

Individual treatments 0·37 (P = 0·05), 0·50 (P = 0·01).
Chemical means 0·22 (P = 0·05), 0·30 (P = 0·01).
Concentration means—not significant at P = 0·05.

Ammonium sulphamate was ineffective even in 70 per cent. solution—in fact it sometimes appeared to favour regrowth slightly, acting perhaps

as a nitrogenous fertilizer. With May cutting 2,4-D ester at most concentrations gave significantly poorer control than the other 2,4-D compounds, and similarly but to a lesser extent with April cutting. 2,4-D amine appeared to be slightly more effective than the sodium salt. In the April experiment 5 and 10 per cent. concentrations were not significantly different but both were significantly better than 2½ per cent.; in the May trial there was a similar but slighter and non-significant tendency. A 5 per cent. 2,4-D amine solution appeared to be somewhat more effective than a 10 per cent. solution, as discussed below. 2,4-D ester was more effective when applied in mid-April than in mid-May, the reverse of what occurred with 2,4,5-T in 1953 (Tables 5 and 6). No clearly consistent tendency in this direction was apparent with 2,4-D (sodium salt) and 2,4-D amine in 1955. In 1956, 2,4-D compounds and the sodium salt of 4-chloro-2-methylphenoxybutyric acid (MCPB) were investigated (Table 10).

TABLE 10. *Percentage Regrowth after Stump Treatment on 1 May 1956*

Untreated 54·0

Chemical used	*Concentration*						*Mean*	
	2½%		5%		10%			
2,4-D sodium .	2·9	(0·55)	0·51	(0·16)	0·31	(0·10)	1·2	(0·27)
2,4-D amine .	1·6	(0·33)	0·35	(0·12)	0·59	(0·19)	0·8	(0·21)
MCPB .	5·7	(0·79)	2·09	(0·44)	0·37	(0·12)	2·7	(0·45)
Mean .	3·4	(0·56)	0·98	(0·24)	0·42	(0·14)		

Minimum significant differences (transformed data):

Individual treatments, 0·14 ($P = 0·05$), 0·19 ($P = 0·01$).
Means, 0·08 ($P = 0·05$), 0·10 ($P = 0·01$).

There was significant interaction between kind of chemical and concentration but this was relatively slight compared with the main effects. MCPB was less effective than 2,4-D compounds except at 10 per cent. concentration. 2,4-D amine gave significantly better control than the sodium salt at the 2½ per cent. concentration. Five and 10 per cent. solutions were significantly more effective than 2½ per cent. but only with MCPB was 10 per cent. significantly better than 5 per cent. As in previous experiments 5 per cent. 2,4-D amine seemed to be more effective than 10 per cent.

Discussion and Conclusions

The amount of regrowth occurring after hand pulling of cotton in the Gezira varies considerably and depends largely on the efficiency of the operator. If carefully carried out it may virtually eliminate regrowth but a few broken roots are usually left in the soil and later produce a small amount of ratoon growth. In badly pulled fields—fortunately rare—ratoon density may reach a hundred or more per acre, and in some

cases intractable plants may be cut instead of pulled. Even at the Gezira Research Farm where pulling is carefully performed some thirty ratoons per acre have sometimes been recorded in individual fields. In the Gezira varying but usually small numbers of cotton ratoons, often up to twenty or thirty per acre, are to be found in some fields in most seasons. These numbers represent about 0·1 per cent. of the original plants and can probably be regarded as a very approximate measure of ratoon incidence following 'average' pulling in the Gezira; any alternative method of controlling regrowth would have to be at least equally effective.

To attain this standard cotton roots would have to be cut at rather more than 6 inches below soil level (Table 3) and in some seasons and areas cutting might have to be considerably deeper, thus approaching pulling in which the first foot or so of the tap root is removed (sometimes 18 inches in large plants). Such deep cutting could be accomplished by machine, but the economics of the method and its affect on the soil would need to be considered. Mechanized pulling is also being investigated, but here again almost 100 per cent. effectiveness is necessary unless plants missed by the pulling machine are afterwards to be removed by hand.

Stump treatment with 5 per cent. 2,4-D amine solution reduced regrowth to 0·1–0·35 per cent. (Tables 7–10), and improved application techniques and possibly more effective chemicals might reduce this figure still farther, e.g. the effectiveness of herbicides dissolved in other solvents should be investigated. Cotton is extremely sensitive to 2,4-D compounds as evidenced by the markedly abnormal growth with thickened, elongated, and 'frilled' leaves which resulted from application of minute quantities of 2,4-D sprays. For stump application the amine was slightly superior to the sodium salt and both were much more effective than 2,4-D ester, possibly in part associated with the volatility of the latter. Ten per cent. 2,4-D amine solution often appeared to be less effective than 5 per cent. (Tables 8–10) but the reasons for this are not known; possibly under certain conditions the stronger solution kills the tissue in the immediate vicinity of the wetted surface so rapidly that it is to some extent prevented from reaching the deeper lying parts of the tap root.

These tentative conclusions apply only to the Gezira and would probably need modification for other areas with different climatic, soil, and agricultural conditions. Thus cotton plants grown in the fertile soil of the Gash Delta in the north-eastern Sudan are often much larger than those in the Gezira, sometimes reaching 7–8 feet in height and possessing correspondingly thicker stems and deeper, more robust roots. Hand pulling of such plants is an arduous, difficult, and lengthy task and their destruction by stump treatment might entail heavier applications of herbicides than are needed in the Gezira. With suitable machinery cutting and stump treatment could probably be accomplished in one operation and might be of use if mechanical methods for end-of-season destruction of cotton plants should prove to be impracticable or uneconomic.

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CRABS AS PESTS OF RICE ON TIDAL SWAMPS

H. D. JORDAN

(*West African Rice Research Station, Rokupr, Sierra Leone*)

Summary

Damage to rice seedlings by crabs, mainly *Sesarma huzardi*, has in recent years severely hampered experimental work at the West African Rice Research Station. Experiments were carried out in order to find means of overcoming this. Use of chemicals on rice lands must be confined to those of minimum toxicity to humans.

The main breeding of the crabs takes place in the dry season, and appears to follow two independent cycles, one of which is associated with high spring tides.

Technical benzene hexachloride (BHC) was found repellant in baits but effective as a contact poison. Lindane (gamma BHC) was quicker-acting at equivalent concentrations and may be of more use in poison baits.

Spraying with a 10 per cent. suspension of technical BHC (containing 6·5 per cent. gamma isomer) has been adopted as a routine measure and has proved effective in killing crabs. Moreover, even if only slightly affected, crabs stopped feeding.

Spraying must be carried out when suitable conditions prevail. The periods following high spring tides in the dry season were the best.

Application of technical BHC containing 6·5 per cent. gamma isomer, at ½ oz. per square yard, to rice seedlings in the nursery gave considerable protection to the seedlings after transplanting under normal conditions.

In 1934 the Sierra Leone Department of Agriculture established a station at Rokupr to investigate problems of rice growing on the tidal lands of the Scarcies rivers. In the early records of the station there are references to damage caused by crabs to newly planted rice seedlings on these tidal lands. In the years 1934 to 1943 crabs were recorded as plentiful on the Rokupr farm, and in some of these years there is mention of 'heavy damage'. On close examination of the records, however, it is evident that this damage was practically confined to land adjacent to bunds and drains, and that in general the planting of guard rows around experimental material was deemed sufficient protection.

From 1944 to 1947 the major part of Rokupr farm was empoldered and tidal influence excluded in an attempt to grow rice as a rain-fed crop. Extremely acid soil conditions, inimical to the growth of rice, developed on a part of the area and crabs virtually disappeared. In 1948 tidal conditions were reintroduced and in this and the two succeeding years only minor trouble from crabs was encountered. In 1951, however, crabs became very plentiful on the farm and caused heavy damage. Within 2 weeks of planting the seedlings on an area of nearly 3 acres were completely destroyed and very serious damage, with reduction of yield, occurred on other parts of the farm. Several lines of selections planted as single plants were severely damaged and had to be abandoned. In 1952 there were considerable losses but damage was not on the whole so serious. In 1953, however, there were again

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very widespread losses, but since 1954 damage has again been reduced, though it is probably considerably more than the 'heavy damage' of the early years of the station.

After the heavy losses of 1951 it became apparent that the experimental work of the station, which had been newly reconstituted as the West African Rice Research Station, would be severely hampered unless the problem of crab attack on newly planted rice seedlings could be solved. It appeared, however, that little was known about the habits of these crabs and that there was little published work on this or related subjects. Some preliminary investigations were started in 1954 and continued through the 1955 season.

Biology of the Crabs

Four species of crab appear commonly on Rokupr farm although three of these species occur only in small numbers. Specimens were tentatively identified by the West African Fisheries Research Institute and more positive identifications were later obtained from M. Th. Monod, Director of the Institut Français d'Afrique Noire at Dakar. The species, of which the one of major importance is placed first, are:

Sesarma (*Chiromantes*) *huzardi* Desmarest 1825.
Sesarma (*Chiromantes*) *alberti* Rathbun 1921.
Sesarma (*Holometopus*) *angolense* Brit. Cap. 1864.
Sarmatium curvatum H. M. Edw. 1837.

Collection of crabs was made daily from November 1954 to November 1956. Locally-made wicker traps were used; these were baited with cassava and distributed in the drains on the farm. Some hand collection was also carried out. Over 75,000 crabs were caught and examined in this period, counts being made of the numbers of males, of females, and of females carrying eggs. The first counts showed a marked falling-off in the proportion of females carrying eggs in the months of July to October. This is the rainy season, and comparison of the figures with those for mean daily temperature showed that this fall was related to a fall in temperature at that time. Monthly figures showing this are given in Table 1.

TABLE 1. *Comparison of Mean Daily Temperature with Percentage of Female Crabs caught carrying Eggs*

	1955		*1956*	
	Temperature °F.	*% of female crabs with eggs*	*Temperature °F.*	*% of female crabs with eggs*
May . .	80·5	31·5	81·6	35·5
June . .	78·4	14·8	80·1	23·3
July . .	77·4	5·4	77·8	3·7
August .	76·6	6·6	75·9	0·9
September .	78·7	0·0	78·4	1·8
October .	79·2	1·1	79·3	5·9
November .	80·1	8·7	79·8	5·5

There was a slight lag between the fall and rise in temperature and the fall and rise in egg production, which was presumably due to actual breeding taking place at an earlier date than when the carrying of eggs was observed.

The dry-season figures showed considerable fluctuations and it was apparent that more detailed examinations of these would be necessary; these were carried out using the chi-squared test. Significant correlation was found between the proportions of females carrying eggs and the states of the tide, and it was thought that this might lie in the number of hours the tide was flooding the rice land each day.

The records from an automatic tide gauge were examined but no correlation was found. A number of other groupings were examined and high significance was found between the figures at high and at low spring tides. The periods: neap tide to neap tide through high spring tide; and neap tide to neap tide through low spring tide, were therefore adopted for the final analysis.

It was apparent from inspection of the daily records that there was another cycle of egg production in addition to and independent of the tidal cycle, and that three main peaks occurred at approximately 11-week intervals. No correlation could be found between this cycle and any external factors, and it is assumed to be due to an inherent breeding rhythm of the crabs. The daily collection figures for each of the two dry seasons were therefore divided into three $5\frac{1}{2}$-week periods of maximum egg carrying and three alternating similar periods of minimum egg carrying, and catches at low and high spring tides were treated separately within these periods. A summary of the figures is given in Table 2.

TABLE 2. *Percentage of Female Crabs caught carrying Eggs in the 1955 and 1956 Dry Seasons*

Breeding cycle	*High spring tides*	*Low spring tides*	*Mean*
Maximum . .	30·1 †	22·9	26·5 †
Minimum . .	23·5 *	18·2	20·8
Mean . .	26·8 †	20·5	23·6

† Highly significant difference (P = 0·01). * Significant difference (P = 0·05).

These figures show that egg carrying fluctuated in the dry season on an 11-week cycle and that superimposed on this was a similar fluctuation on a 4-week cycle associated with the high spring tides.

It was also noticed that males always outnumbered females and it was at first thought that there was a fluctuation in the percentage of females in the total catch, correlated with tides. On close examination of the figures for the two years, however, it is found that this apparent fluctuation was not significant.

Control of Crabs

In 1935, when damage from crabs was first noticed at Rokupr, fumigation with Cyanogas had been attempted. It was, however, possible to treat only crab holes in bunds by this method, which was costly and of doubtful effect as little reduction of the crab population was noticed. Similar poor results with this method were reported in Malaya in 1936 [1]. In 1939 and the following two years a flock of Muscovy ducks had been herded on the rice land in the dry season. They ate large numbers of crabs, but they appear to have exercised no effective control, for at the end of these three years crabs were still recorded as plentiful. In 1951, when crab damage became pronounced, hand collection and trapping were started. Locally made wicker traps were baited with cassava and placed in drains and on the edges of the rice land where crabs were plentiful. Seventeen thousand crabs were caught and destroyed in that year, a similar number in 1952 and 32,000 in 1953, but in spite of this there was no appreciable reduction in the crab population. It was thus evident that chemical means of destroying the crabs would have to be found, though such a method of control is complicated by the fact that the local population draw drinking water from the river, and also that fishing is widespread. It was decided for this reason that no general poison could be used.

While crabs and other decapods have caused trouble in many countries, the problem at Rokupr was very different from that reported elsewhere, the nearest to it being the destruction of cotton and other seedlings in the southern United States by prairie crawfish [2, 3, and 4]. Balss [5] refers to *Sesarma* species, among others, as pests, but damage was caused by many different types of crabs, lobsters, and crawfish. Ghosh [6] reports crabs damaging rice in India, but damage was limited and occurred only on grown plants and no control other than hand collection appeared necessary.

In Sierra Leone crabs have been reduced in numbers by the Medical Department by spraying with Paris Green or by blocking their holes in bunds with a mixture of one part of Paris Green to five parts of mud. A similar method was effectively used in 1951 against land crabs destroying seedlings in a Forestry Department nursery. In Malaya, however, Paris Green was considered doubtfully effective and slaked lime and Tuba root (derris) were found to give the best control against mud lobsters (*Thalassima anomala*, Herbst.) [7]. Lime has also been used with some success against prairie crawfish (*Cambarus hagenianus*, Faxon) in the United States [2]. This pest has also been controlled to a varying extent by a turpentine : creosote emulsion [4] and by calcium carbide and carbon bisulphide [2]. These methods are, however, all directed against the pests in their burrows, a practice quite impracticable with the numbers of crabs at Rokupr.

Trapping with smooth-sided pots, sunk in the ground and baited, is carried out in Ceylon and Malaya [5] and was suggested originally for Rokupr. The tidal conditions on the rice land make this impracticable, and wicker traps were used. Another method, impracticable at

Rokupr but used in the United States, is the lowering of the water table.

The use of poison baits was considered to be a promising approach. One part of 5 per cent. DDT to ten parts of sweetened rice was found effective against crabs in Bombay [private communication] and DDT baits as well as sprays are used to control crawfish in the United States [3]. In Madras, Warfarin[1] baits, laid in order to kill rats, killed a species of land crab, *Paratelphusa hydrodromus*. H. [8].

Trials with Poison Baits

Laboratory trials. Trials were first carried out in the laboratory, in which the behaviour of single crabs was observed when offered different baits. The substances available were: Technical BHC (benzene hexachloride) in two commercial preparations—Agrocide Dispersible Powder containing 6·5 per cent. gamma BHC and Agrocide 3 containing 0·65 per cent. gamma BHC; DDT in 50 per cent. strength as Didimac 50; and sodium fluorosilicate. These were added in the proportion of one part to ten parts of grated cassava or a rice bran : groundnut cake mixture. A small quantity of bait was placed in a glass tank with a single crab and a little water.

In the first trial the cassava bait was used. This proved unsatisfactory as it disintegrated in the water. However, although only the control crab was observed to feed, the toxic substances dispersed in the water appeared to act as contact poisons; all crabs except the control died, those with the BHC preparations dying first.

Further laboratory trials were carried out with the tanks tilted so that the bait was not in the water. With the cassava bait and BHC preparations crabs were affected but did not die; on being removed, washed, and placed in clean water they fully recovered. With the rice-bran mixture as bait the crab with the Agrocide Dispersible Powder died and those with the other BHC preparation and with DDT were affected but not killed. The control and the crab with sodium fluorosilicate were unaffected.

In the following year two other commercial preparations, Sorexa Warfarin[1] compound, and Gammalin 20—containing 20 per cent. pure gamma BHC, were tested in similar trials, using grated cassava as the basis of the bait. Gammalin proved extremely effective but Warfarin had no effect. A further experiment compared technical BHC and gamma BHC (Agrocide Dispersible Powder and Gammalin 20), at rates giving equal amounts of gamma isomer, at the concentration used in the first experiment and at half that concentration. In no case did any crabs die, but all were affected (apart from the control). The first treatment to take effect was that with gamma BHC at the full concentration. This was followed by the half concentration, and then by the technical BHC treatments in the same order.

Field trials. Other trials were carried out in the field, using cages having ½-inch-mesh galvanized-wire netting on all six sides, the tops being in the form of tightly fitting lids. The bottoms were 3 feet square

[1] Warfarin = 3-γ-acetonylbenzyl-4-hydroxycoumarin.

and were sunk a few inches into the rice swamp. Ten crabs were placed in each cage with bait consisting of 4 ounces of grated cassava with a 10 per cent. admixture of the various toxic substances. At the end of 4 days the numbers of active, affected, and dead crabs were noted, and are recorded in Table 3.

TABLE 3. *Classification of Crabs after Exposure for 4 Days to Poison Baits*

Toxic substance	*Active*	*Affected*	*Dead*
BHC (Agrocide Disp. Powder)	5	2	3
BHC (Agrocide 3) . .	6	1	3
DDT (Didimac 50) . .	7	0	3
Sodium fluorosilicate . .	10	0	0
Control . . .	9	0	1

It was evident that BHC was the most promising of the substances used, although it has a powerful smell and crabs seemed to be repelled by it. In a further trial similar to the last this substance was used with sugar-cane as bait. Lengths of sugar-cane were peeled and placed in a suspension of 1 gm. Agrocide Dispersible Powder in 100 c.c. water in pressure flasks which were evacuated until bubbling ceased. Air was then admitted and the cane allowed to soak for several hours and then washed. Four cages of ten crabs each were given treated, and a fifth cage untreated, cane. Crabs were observed to feed in all cages. After 4 days an average of five active, four paralysed, and one dead were found in the treated cages, while in the untreated cage all the crabs were active.

Trials with Contact Poison

The first laboratory trial with poison bait had given an indication that technical BHC was effective as a contact poison against crabs, and a series of trials were therefore carried out using Agrocide Dispersible Powder suspensions. Later work indicated that the gamma isomer was the main effective constituent, so concentrations are expressed below as parts per million of gamma BHC.

Laboratory trials. Crabs were placed singly in beakers containing suspensions with varying concentrations of gamma BHC. At 65 p.p.m. the crab was affected within 1 hour and dead within 4. At 6·5 p.p.m. it was affected within 4 and dead within 24 hours. At 0·65 p.p.m. it was affected within 24 but not dead after 72 hours. At 0·065 p.p.m. the crab remained unaffected throughout, as also in the tap-water control.

In the field, however, such prolonged contact would not be likely to occur and a further trial was carried out in which crabs were sprayed with an Agrocide suspension containing 65 p.p.m. gamma BHC. When sprayed and placed in a dry beaker crabs were affected within 1 hour and dead within from 2 to 12 hours. After spraying and placing crabs in clean water an effect was noticed in 2 hours and death occurred in 5. When the crabs were sprayed and immediately washed in running tap water before being placed in clean water an effect was noticed in 5 and

death occurred within 24 hours. It was apparent therefore that even momentary contact with BHC was effective.

To dispose of doubts whether the effective substance (when used as a contact poison) was the gamma isomer of BHC or another (possibly the delta) isomer, further trials were carried out with lindane (Gammalin 20, containing only the gamma isomer). Single crabs were placed in beakers with 100 c.c. of varying concentrations. At 65 p.p.m. gamma BHC the crab was affected very quickly and dead within 1½ hours. At 6·5 p.p.m. the first sign of an effect was not so quickly visible, but the crab also died within 1½ hours. At 0·65 p.p.m. it was affected in 4½ hours and dead within 24. At 0·065 p.p.m. and in the tap-water control it was not affected.

A further experiment compared Agrocide Dispersible Powder with Gammalin 20 at equal gamma-isomer concentrations. Results are shown in Table 4.

TABLE 4. *Time of Action of different Concentrations of BHC Preparations on Single Crabs*

Preparation	*Concentration of gamma BHC in suspension, p.p.m.*	*Affected*	*Paralysed*	*Dead*
Agrocide	65	30 mins.	60 mins.	90 mins.
Gammalin	65	3 mins.	10 mins.	20 mins.
Agrocide	6·5	90 mins.	150 mins.	180 mins.
Gammalin	6·5	30 mins.	60 mins.	90 mins.
Agrocide	0·65	5 hrs.	23 hrs.	47 hrs.
Gammalin	0·65	1 hr.	1½ hrs.	3 hrs.
Control		not affected		

The quicker effect of Gammalin may be due to its forming a finer suspension on dilution. (Gammalin 20 is a liquid.)

Field trials. Ten crabs each were placed in cages as described above (p. 201), and some rice was planted in each cage. The crabs were sprayed with 100 c.c. of suspensions of Agrocide Dispersible Powder. After 5 hours a number were seen to be sluggish in the treated cages. The results after 2 days are given in Table 5. It was noticeable that only in the control cage—sprayed with tap water—had any rice been eaten.

TABLE 5. *Classification of Crabs after Spraying with various Concentrations of BHC*

Concentration of gamma BHC	*Active*	*Affected*	*Dead*
650 p.p.m. . . .	0	7	3
488 p.p.m. . . .	0	6	4
325 p.p.m. . . .	0	6	4
163 p.p.m. . . .	10	0	0
Control . . .	10	0	0

It was apparent that under the conditions of this experiment concentrations of 325 p.p.m. gamma BHC or more were effective.

In the above trial the crabs themselves were sprayed. Under normal field conditions, however, this is unlikely to occur, for when approached the crabs go into their holes. A trial was therefore made of general spraying with a concentration of 650 p.p.m. gamma BHC (1 lb. Agrocide Dispersible Powder in 10 galls. water). A length of drain with its adjacent bunds was sprayed with 4 gallons of this suspension. Very few crabs came into direct contact with the spray although they were abundant in the drain before the operator arrived. This spraying was carried out as soon as the tide had receded and the drain contained numerous puddles. Five hours later no active crabs could be seen. Small crabs were mainly dead and larger ones were dying. Three hundred and fourteen dead and dying crabs were recorded in 20 yards of drain of 5 feet width. After 24 hours, when the tide had twice ebbed and flowed in the drain, a few active crabs were then seen but dead and dying crabs were still very noticeable, many holes having dying crabs at the entrances. Some affected crabs were to be found many yards away from the drain.

A similar spraying carried out a few days later when the tide was rising and light rain was falling proved less effective. After 24 hours some dead and dying crabs were seen but there were still many active ones, particularly in the holes. It is apparent that the conditions for spraying have to be carefully chosen.

Trials on Protection of Rice Seedlings

As technical BHC appeared repellent to crabs it was thought that rice seedlings treated with this substance might suffer less from crab attack than ordinary seedlings. Gough and Woods [9] reported that wheat-bulb-fly larvae were apparently prevented from attacking wheat seedlings grown from seed treated with gamma BHC. A small area of rice nursery was therefore dusted with Agrocide Dispersible Powder at the rate of 1 ounce per square yard. The seedlings were pulled after 1 week and used together with untreated seedlings in the following trial.

Five cages were placed in the rice land and each was planted with sixty-four seedlings arranged in eight rows of eight seedlings each. Various combinations of treated and untreated seedlings were used. Fifty crabs were then placed in each cage and left for 2 days, at the end of which time the seedlings were examined. In one cage all seedlings had been treated and 59 per cent. survived; in another with all untreated seedlings 27 per cent. survived. In a third cage two opposite quarters were planted with treated seedlings and the other two with untreated. Of the treated seedlings, 59 per cent. survived, but only 13 per cent. of the untreated. A fourth cage had a block of sixteen untreated seedlings planted in the middle with a double row (forty-eight plants) of treated seedlings surrounding it. Here 38 per cent. of the treated seedlings survived, but 69 per cent. of the untreated. The fifth cage had equal numbers of treated and untreated seedlings planted in chequer-board fashion and 19 per cent. of the treated and 31 per cent. of the untreated survived; the results for this cage showed no significance by the chi-squared test. This trial was thus inconclusive. While the first three cages appeared to show that seedlings were afforded some degree of

protection by the treatment, the fourth cage gave a contrary indication. It was noticeable in all cages that the seedlings round the edges were more attacked by crabs than those in the centre and this could explain the result in the fourth cage.

In a further experiment five 1-square-yard areas of a rice nursery were treated with 1 oz., ¾ oz., ½ oz., ¼ oz., and no Agrocide Dispersible Powder respectively. After 5 days, sixty-four seedlings, matched for size, from each of these were planted, each lot in one of the five cages, and twenty similarly sized crabs put in each cage. The number of seedlings destroyed was recorded after 24 hours. This procedure was repeated daily for 5 days, the treatments being randomized in the cages in such a way as to make the results capable of analysis as a Latin square. While on the average the greatest damage occurred in the controls and in the seedlings with the lightest application of BHC the differences were not significant. However, there was a significant difference between the degrees of crab attack on different days. It was noticed, moreover, that, while in the cages of untreated seedlings some were cut off at ground level and destroyed, in the cages of treated seedlings many of the plants cut off had not been eaten but were left lying on the ground. It seemed possible therefore that the crabs, having cut off a treated seedling rejected it as food and then cut off others; this might explain why the damage was heavier than expected in the treated cages.

A third experiment was therefore carried out, in which an alternative food supply was made available. Only half of each cage (thirty-two seedlings) was used for the experiment (which was otherwise identical with the previous one), the other half being planted entirely with untreated seedlings which were not recorded. The results from this experiment are given in Table 6.

TABLE 6. *Crab Damage to Treated Rice Seedlings in the Presence of an Alternative Food Supply*

Treatment. Agrocide per sq. yd.	*% seedlings destroyed*
1 oz.	17·5
¾ oz.	16·3
½ oz.	16·9
¼ oz.	28·8
nil	31·3

Least significant difference (P = 0·05)—10·6 per cent.

Treatments of ½ oz., or more, of Agrocide Dispersible Powder per square yard of nursery had thus significantly reduced the damage to the seedlings. The ¼-oz. treatment was ineffective. There was high significance between the damage done on different days.

The plots of rice from the last two experiments were allowed to continue growth and their yields recorded. There were, however, no significant differences in yield, the remaining plants having tillered well and filled up the gaps.

Discussion

It is possible that good results can be obtained against crabs with poison baits by the use of lindane which is non-repellant and by the use of attractive bases for the baits. The experiments outlined above, however, gave more promising results from spraying. For this purpose technical BHC, which is cheaper than the purified gamma isomer, can be used. Spraying must, however, be carried out under the optimum conditions to be fully effective. It appears that the most favourable conditions occur after high spring tides in the dry season, when puddles are left on the ground and are not disturbed by following tides or rain. The observations on the biology of the crabs indicate that the dry season is also the period of maximum breeding, so from all points of view it is the best. Routine spraying at these times has thus been adopted at the West African Rice Research Station and has shown good effect in killing crabs. Even when it does not kill them it quickly stops them feeding. During the first year of this practice crab damage has been much less noticeable. BHC is said to be toxic to fish but no dead fish were found at Rokupr after spraying. Mud skippers (*Periophthalmus koelreuteri*, Pallas) were abundant and seemed to be quite unaffected by the spray.

The treatment of seedlings in the nursery with technical BHC appears to give some degree of protection to them after transplanting when there are alternative sources of food supply. It is important when dealing with selections and hybrids that individual plants survive, and for this reason the treatment of such plants in the nursery with $\frac{1}{2}$ ounce per square yard of technical BHC containing 6·5 per cent. gamma isomer is being adopted as a routine measure.

It is expected that the combination of these two practices will greatly reduce the crab damage to experimental material.

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FURTHER STUDIES ON THE SEX RATIO IN FOWL

R. COLES

(*Ministry of Agriculture, Fisheries and Food, London*)

Summary

The data recorded in this investigation support the earlier conclusions that with pure-mated pullets more females than males are produced at fertilization. It seems that older females *in continuous lay* tend to show a still wider primary sex ratio. While this experiment did not manifest a significant difference between pullets and hens, the same tendency was observed in previous years and in another flock where similar details on sex ratios have been recorded. The primary sex ratio does not show such a marked departure from parity among the offspring of cross-mated stock—at any rate for pullets, and it does appear that the effect of cross-mating may offset the apparent widening of the sex ratio with continued laying.

The incidence of greater female than male embryonic mortality with low hatching rates was not so manifest in this investigation as in earlier experiments although this general conclusion has been reached by other workers. There does, however, seem to be a tendency for female embryos from pure-mated parents to succumb more easily than female embryos from parents cross-mated. This behaviour of female embryos under stress and the apparent tendency of female embryos from cross-mated stock to offer greater resistance to mortality is analogous to that of the male in mammals. But post-natally the similarity does not continue, for a differential mortality rate is not evinced with fowl. In the case of mammals the pre-natal and post-natal differential mortality has been attributed to deleterious sex-linked genes and the greater resistance of the male offspring of wide racial crosses has been ascribed to the effect of heterosis. The explanation does not entirely fit in the case of fowl because of the failure of the mortality pattern to be continued post-natally, but no other explanation can be offered. No convincing reason can be put forward for the inequality of the primary sex ratio although, in view of the tendency for this inequality to increase with continued high-level laying, it is tentatively suggested that the reason may be the influence of some endocrinal activity related to the ovarian tract. The possibility of the blood pH of the male influencing the primary sex ratio is discussed, although the widening of that ratio with laying continued into the second year would suggest that the female does exert some influence whether or not the influence of the male is a major consideration.

In a recent communication [1] the conclusion was reached that females exceed males in number at the primary stage, but that this departure from parity might be less marked with the offspring of cross-mated parents compared with purebred stock. The former conclusion was based on an analysis of the sex of the embryos in those hatching eggs of an experimental breeding flock of White Leghorns which had failed to hatch, and the number of chicks of either sex which completed the full term of incubation. Over a period of 2 years the primary sex ratio of this flock has ranged from 47·7 to 45·4 per cent. males with an average of 46·25 per cent. While this relatively large disparity in the primary sex ratio of this purebred flock showed little variation over the 2-year period, the claim that the primary sex ratio of crossbred progeny more closely approaches parity rests on much more slender evidence. This conclusion was based on the greater number of males (about 52 per

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cent.) hatched at a large hatchery from sex-linked matings compared with a secondary sex ratio of approximately 50 per cent. with hatcheries producing both pure and crossbred chicks. It was also noted that the percentage of males at hatching had shown a small but continued increase at a number of hatcheries as the proportion of purebred chicks produced had declined in favour of crossbreds.

The data from the hatcheries could be taken to indicate that the primary sex ratio of crossbreds is narrower than that of purebreds, or it might be indicative of a change in the differential mortality between the sexes during incubation. In the author's experimental work cited above a greater number of female than of male embryos died during incubation and, as the hatching rates decreased and so presumably stress factors had increased, the percentage of female embryos succumbing also increased. Attention has been drawn to this differential death rate between the sexes by several workers [2, 3]. The hen is the heterogametic sex and on the analogy of Huxley's [4] statement that in the human species male children of wide racial crosses show a greater survival rate before and after birth, the hypothesis could be advanced that the female embryonic mortality in fowl should not greatly differ from that of males in the progeny of cross-matings. Without comparative figures for prenatal deaths and the post-natal sex ratio for both purebred and crossbred progeny, this opinion must remain surmise. The value of employing hatchery ratios to support the hypothesis put forward is dubious, for not only is manual sexing inaccurate to varying degrees, but the value of the figures may be further impaired by the age of the parent birds supplying the eggs. This last point is suggested by the fact that the author found in the experimental flock that hens tended to produce a greater number of female embryos at fertilization than pullet parents, although the numbers of yearlings and older birds were too few for the result to be statistically significant. The conclusion did, however, gain some support from the fact that most hatcheries report a seasonal change in the sex ratio, in that slightly more males are hatched in the early part of the season and more females towards the close of the hatching season. This common finding would add support to the opinion elsewhere expressed by the author that continued laying leads to an increase in the proportion of females at the primary stage.

The several conclusions advanced are therefore:

1. With purebred pullets more females than males are produced at the primary stage.
2. With long continued laying this preponderance of females is emphasized.
3. With cross-breeding the departure from parity in the sex ratio is not so marked.
4. The mortality rate among female embryos is greater than that found with males and this differential embryonic mortality will reflect good or poor hatching.

The evidence for (1) and (4) is based on experimental work although admittedly with only one flock and there may be strain differences

accounting for the particular findings [5]. The basis for statements (2) and (3) is the information garnered from hatcheries keeping detailed records, and must be admitted to be of doubtful value. With the intention of securing more precise information on these two points and seeking further confirmation of the other conclusions advanced, the following experiment was carried out.

Experimental

Eight semi-intensively managed pens of twelve White Leghorn pullets were set up, the birds being drawn from full-sister groups of the White Leghorn flock previously mentioned. To each pen three White Leghorn hens were added from the same flock. These hens had been in almost continuous lay for approximately 20 months. The pullets had been recorded over 3 months ending at 31 December 1955 and then thrown in a moult and brought back into lay by March 1956 when the experiment began. Four of the pens were sired by White Leghorn cockerels; the remaining four pens were headed by Brown Leghorn males from a closed flock with a high coefficient of inbreeding. All pens received a ration similar in type but differing in the origin of the fishmeal. Four samples had been obtained and, while on chemical analysis they showed very similar protein levels, it was believed that they had suffered varying degrees of damage through heating. It was hoped that variation in the quality of the fishmeal would result in stress conditions during incubation which would give rise to marked differences in the hatching rates. This hope proved moderately well founded and the possible reason for the variation in hatching is reported elsewhere [6], but it did not appear that the colour differences in the meals, due presumably to the Maillard reaction, indicated material damage to the amino-acid contents as the egg production of all groups was approximately the same. Each of the four rations was fed to one pen of birds mated pure and one cross-mated. These four groups were denominated A, B, C, and D.

Of the original ninety-six pullets and twenty-four hens mated, nine pullets—not more than two from any one pen—were discarded and their past records disregarded as they failed to lay at near the average of their pen mates. The experiment was begun in early April and eggs were collected over a period of 72 days. The pullets laid at an average rate of 71 per cent.; the hens at 57 per cent. All eggs laid were set with the exception of seventy-six pullet eggs and nineteen eggs from the hens which were broken, cracked, or badly mis-shapen. All those eggs which failed to produce a chick were opened and examined and, if fertile, the sex of the embryo distinguished—if possible. With embryos younger than 5 or 6 days no attempt was made to distinguish sex. The chicks which hatched were sexed at 8 weeks old by visual inspection; those dying before that age were subject to post-mortem examination for cause of death and the sex determined during that examination.

Results and Discussion

The details of the hatching rates and the sex of embryos (when determined) and of the hatched chicks of each group are set out in Table 1.

TABLE 1. *Hatching Results and Sex of Embryos and Chicks Hatched*

Group		Pen*	No. of birds	Fertile eggs	Hatch of fertile eggs %	Dead embryos			Hatched chicks		Total		Primary+ sex ratio % males
						Male	Female	Unsexed	Male	Female	Male	Female	
PULLETS	A	1(P)	11	376	84·6	17	30	11	163	155	180	185	49·3
		2(C)	11	426	85·7	24	29	8	165	200	189	229	45·2
	B	3(P)	10	505	78·4	46	54	9	183	213	229	267	46·2
		4(C)	11	486	88·1	26	27	5	208	220	234	247	48·6
	C	5(P)	10	430	68·6	49	70	16	143	152	192	222	46·4
		6(C)	12	607	80·1	46	65	10	251	235	297	300	49·7
	D	7(P)	10	417	54·2	62	107	22	110	116	172	223	43·5
		8(C)	12	584	65·7	74	99	27	182	202	256	301	46·0
Totals				3,831							1,749	1,974	47·0
HENS	A	1(P)	3	96	77·1	7	11	4	36	38	43	49	46·7
		2(C)	3	133	89·5	3	9	2	50	69	53	78	40·5
	B	3(P)	3	152	65·8	20	29	3	51	49	71	78	47·6
		4(C)	3	128	82·8	11	10	1	53	53	64	63	50·4
	C	5(P)	3	91	51·6	16	23	5	20	27	36	50	41·9
		6(C)	3	83	84·3	2	9	2	31	39	33	48	40·7
	D	7(P)	3	121	47·9	25	30	8	25	33	50	63	44·2
		8(C)	3	102	72·5	10	17	1	37	37	47	54	46·5
Totals				906							397	483	45·1

* P = Mated pure. C = Cross-mated. + On basis of sexed chicks and dead embryos.

From this table it will be seen that the number of females produced at fertilization was strikingly in excess of the males with both the hen and pullet parents. The percentage of females produced at the primary stage from the hen matings was greater than that recorded for the pullets, but not significantly so. Nevertheless it is of interest to note that the primary sex ratio with the pullets was 47·0 per cent. males and with the hens 45·1 per cent., and that these figures very closely approximate to the averages recorded for the previous 2 years in this flock, viz. 46·3 and 44·5 per cent. respectively. The number of hens previously recorded

TABLE 2. *Primary Sex Ratio observed in Brown Leghorns over 3 and 4 years. (Data: A. W. Greenwood)*

	Constant Environment			*Controls*		
	Males	*Females*	*% Males*	*Males*	*Females*	*% Males*
1st year .	1,339	1,352	49·8	1,120	1,192	48·4
2nd year .	726	854	45·9	1,120	1,276	46·7
3rd year .	347	400	46·5	899	905	49·8

Record of sixteen birds in the Control Group maintained over four laying cycles

	No. of embryos and chicks sexed	*% Males (P.S.R.)*
1st year .	2,068	48·4
2nd year .	2,137	46·8
3rd year .	1,686	49·5
4th year .	1,505	51·8

was only sixteen, but it seems clear that, if the results of the 3 years be aggregated, the earlier suggestion that the primary sex ratio of hens compared with pullets shows a greater percentage of females gains further support. These figures for the primary sex ratio are based on the sex of the hatched chicks and the sex of the dead embryos where this could be determined. The number of unidentified embryos amounted to only 3 per cent. of the fertile eggs. Hays [7] has presented evidence to support his view that there is higher female embryonic mortality during the first 5 days of incubation. If this is so, then the ratios here presented would be subject to a very slight decrease in the number of males, but Jull [8] did not consider that there was differential embryonic mortality prior to the ninth day of incubation.

The possibility of the greater number of females at the primary stage being a strain characteristic of this closed flock was considered. In that event it was possible that the characteristic might be further emphasized in those superior pullets retained for a second year. However, a similar tendency was found in another flock which has been closed for many years (A. W. Greenwood, personal communication, 1956). The figures for this flock are shown in Table 2 and relate to two groups of Brown

Leghorns, one of which was kept under constant environmental conditions while the controls were managed in customary intensive housing. The experimental birds manifested high and fairly steady laying over the first year and then showed a successively lower, though still reasonably even, performance. The controls manifested the expected seasonal variation although laying more eggs *in toto*. It will be noted that the experimental birds showed a more rapid trend towards a greater proportion of females as laying continued and that in both groups this trend was checked as egg production declined.

TABLE 3. *Primary Sex Ratio of Groups Mated Pure and Cross-mated Summary of actual results recorded*

	No. of Birds	*No. of sexed embryos and Chicks*	*Primary Sex Ratio % Males*
Pullets (mated pure)	41	1,670	46·3
Pullets (cross-mated)	46	2,053	47·5
Hens (mated pure)	12	440	45·4
Hens (cross-mated)	12	440	44·8

Test whether mean of transformed Primary Sex Ratio differs from 50 per cent.

	Degrees of freedom	*t*
Pullets (pure)	40	2·91†
Pullets (cross)	45	2·44*
Hens (pure)	11	3·37†
Hens (cross)	11	1·33 (n.s)

† = significant at P = 0·01 level. * = significant at P = 0·05 level.
n.s = not significant.

If, however, the contention that the primary sex ratio more closely approaches parity with cross-mated parents than with pure-mated stock is valid, then one would expect the percentage of males to be reduced below the average for all pullets (or hens respectively) when the sex ratio of only those mated pure is considered. The expectation is partially satisfied when the results with the pure- or cross-mated birds are examined (Table 3). Before considering the group results a test of homogeneity was carried out with the four groups, i.e. pullets mated pure, pullets cross-mated, hens mated pure, and hens cross-mated. The numbers of males, and females, produced by each dam were added—the unidentified embryos being disregarded. From the totals of males and females for each dam, a $2 \times n$ table was constructed for each of the four groups, and a chi-squared test was applied to see if the variation in the primary sex ratio for each bird could have arisen by chance. In none of the four groups was the value of chi-squared high enough to be significant at even the P = 0·05 level, i.e. the deviation of the individual primary sex ratio from the group averages could well have arisen by

chance from a homogeneous group. The percentages for each dam separately were transformed for a significance test using the angular transformation $p = \sin\phi$ and the results are also shown in Table 3. The table indicates that the primary sex ratio of the pullets mated pure differed from 50 per cent. significantly at the P = 0·01 level. The same condition applied to the hens mated pure, but the pullets cross-mated produced progeny in which the proportion of females at fertilization significantly exceeded 50 per cent. only at the P = 0·05 level. The

TABLE 4. *Hatching Rates and Female Embryonic Mortality with Pullet Dams*

Pen no.	*Hatching rate* (%)	*Dead embryos*		
		1. *Male*	2. *Female*	% *Female*
1. (Pure)	84·6	17	30	64
2. (Cross)	85·7	24	29	55
3. (Pure)	78·4	46	54	54
4. (Cross)	88·1	26	27	51
5. (Pure)	68·6	49	70	59
6. (Cross)	80·1	46	65	58
7. (Pure)	54·2	62	107	63
8. (Cross)	65·7	74	99	57

progeny of hens cross-mated did not evince a significant departure from parity in the sex ratio, but this seems to be due more to the relatively high coefficient of variation for the data in this small group than to a genuine difference from the other groups. Two of the twelve hens in the test produced less than ten eggs which affected the straight average of individual hen primary sex ratios. It does, however, appear that with cross-mated birds the primary sex ratio tends to become narrower, and it may be that on occasion cross-mating may be a more potent agent in influencing a trend towards parity in the primary sex ratio than continued laying in promoting a divergence therefrom.

Although generally more female than male embryos died in each group of progeny from each of the eight pens, the relationship between low hatching and a higher proportion of female embryonic mortality was not by any means as consistent as in previous years (Table 4). This may be attributable to the fact that the severe decline in the hatching rate experienced in earlier years was not so manifest on this occasion. Another reason may be that the female embryos from cross-mated parents did not so easily succumb to stress conditions during incubation as those from pure-mated stock. The grouped figures in 1954 with a flock-average hatching rate of 79 per cent. evinced a female mortality rate among the embryos dying during incubation of 58·3 per cent.; in 1955 with a hatching rate of 64 per cent. the corresponding percentage was 64·1, whilst in the 1956 experiment, with an average hatching rate of 76 per cent. with the pullets, the female embryonic mortality was 58·8 per cent. of the total number of embryos dying of which the sex was determined. A strict comparison with previous years is not possible, because it seems clear that the departure of the primary sex ratio from

parity is not so marked with crossbred progeny, while the females from such stock show a tendency to succumb less easily than with the offspring from pure-mated parents. Nevertheless, in the group with the highest hatching rate, viz. pen 4 with 88·1 per cent., the number of dead female embryos was almost the same as that of males. In pen 7 with the lowest hatching rate, viz. 54·2 per cent., 63 per cent. of the dead embryos were females. It is realized that in all pens more females than males were produced at the primary stage, but even so the percentage of female embryos dying with the lower hatching rates was greater than that number which would be *pro rata* to the primary ratio if there were no sex differential in embryonic mortality.

TABLE 5. *Relationship between Embryonic Mortality and Secondary Sex Ratio*

(Unweighted means of results for each pullet. Dams having no eggs hatching out are excluded.)

Embryonic mortality rate	*Pullets (pure)*			*Pullets (cross)*		
	No. of dams	*Mean of S.S.R. minus P.S.R.*	*S.E. of mean* ±	*No. of dams*	*Mean of S.S.R. minus P.S.R.*	*S.E. of mean* ±
0	9	+0·005	0·008	14	−0·0002	0·004
0·1	9	−0·007	0·009	12	+0·004	0·009
0·2	7	+0·015	0·035	10	+0·013	0·015
0·3	5	+0·049	0·021			
0·4	4	+0·064	0·037	9	−0·006	0·035
0·5 and over	5	+0·103	0·032			

A further analysis was carried out to test if the sex ratio at hatching was wider with low hatching rates than with high hatching rates, as more females seem to die under stress with poor incubation results. The data from cross-mated pullets were treated separately from those for the pure-mated birds, but the figures for the hens, being too few, were not employed for this grouping analysis. The embryonic death rates were compared, bird by bird, with the difference between the secondary and primary sex ratios. Individuals where no eggs were hatched out were excluded. The results are shown in Table 5. There does seem to be some relationship between high embryonic death rates and the greater survival of males at hatching, but the method of analysis is rather crude.

When the embryonic death rates for the progeny of the pullets mated pure and those cross-mated are considered, it seems clear that, when due allowance is made for the varying stress sustained by the four groups during incubation, the embryonic mortality was lower in the cross-bred progeny than in that of the pullet parents mated pure (Tables 1 and 6). There are also strong indications that female embryos among the offspring of birds cross-mated are less prone to succumb under stress than the female embryos from parents mated pure. This seems apparent from Table 6. In presenting these figures unsexed dead embryos were included in the calculations of the death rates and were distributed in the ratio of the sexes of those dead embryos for which the sex was deter-

mined and of hatched chicks. The total number of unsexed embryos only amounted to less than 3 per cent. of all fertile eggs. The death rates for each sex were here calculated from the proportion of dead embryos to the total of chicks hatched plus dead embryos.

TABLE 6. *Analysis of Embryonic Mortality among Pullets and Hens Mated Pure and Cross-mated*

	No. of birds	*Embryonic Death Rate**		*Approx. S.E. of difference*
		Males	*Females*	
Pullets (pure) .	38	0·24	0·30	0·03
Pullets (cross) .	46	0·20	0·22	0·02
Hens (pure) .	11	0·36	0·39	0·03
Hens (cross) .	10	0·13	0·20	0·025

* Unweighted average of death rates per laying bird.

N.B. (1) Embryonic deaths include unsexed embryos distributed among males and females in the ratio found among sexed embryos plus hatched chicks for each dam.

(2) Dams having fewer than ten fertile eggs are excluded.

From the evidence presented it seems beyond all doubt that confirmation is given to the conclusion previously reached, that more females than males are produced at fertilization. Dams which had continued with high-level production until their hen year also produced a greater number of females at the primary stage, but in the case of hens cross-mated the ratio did not differ significantly from parity. With hens pure-mated although the actual proportion of females was greater than that found with the pure-mated pullets, it was statistically not significantly so. Nevertheless, in view of the findings from previous years and the evidence produced from elsewhere the hypothesis seems reasonably supported. Some further evidence is presented to support the hypothesis that with crossbred stock the primary sex ratio of the progeny more nearly approaches parity than with purebred progeny. The influence exerted in this direction consequent upon cross-mating tends to be more potent than the opposing trend towards the widening of the primary sex ratio observed in stock which has been in lay for some time.

In this experiment, however, the previously observed fairly close relationship between female embryonic mortality and rates of hatching is by no means so clear-cut. The earlier conclusion that more embryo females die when the hatching rate is low is certainly supported by those pens having well above or well below the average hatching rates of the flock. With the pens showing smaller deviations from the flock average, the relationship is not apparent. It should, however, be pointed out that as the primary sex ratio with crossbred progeny does not show wide departures from parity, and as the female embryos from such matings do not evince quite the same tendency under incubation stress to die more rapidly than males, the clear-cut relationship in previous years with pure-mated stock cannot be expected. But in any case the general tendency for female embryos to succumb to stress more speedily than males has been commented on by others [3].

No conclusive reason can be put forward to explain the difference in the primary sex ratio and why the proportion of females should tend to increase with continued laying. It seems clear that this variation in the sex ratio is connected with continuous laying and not with age. This opinion gains credence from Greenwood's data from which it was noted that high-level laying at a fairly consistent rate over the year was associated with an increasing number of females at the primary stage, but that this trend was reversed when production showed a sharp decrease in the third year—and in the fourth year with the one group so far reported on. It is conceivable that the change in the sex ratio over a period of continued laying is connected with endocrinal activities associated with the ovarian tract. This tentative suggestion would receive some support from the fact that the secondary sex ratio of chicks from hatcheries manifests slightly more males at the beginning of the season (i.e. when most of the supplies are drawn from pullets coming into lay) and rather more females at the close of the season. Why this tendency should be checked by cross-mating is also not capable of any obvious explanation. It would seem, however, that the answer is to be sought for by investigating the influence of the male.

The suggestion has been made by McWhirter [9] that in mammals a below-average blood pH in the male is associated with an excess of females over males in the progeny. Weir and Clark [10] found that in mice the blood pH was correlated with the sex ratio, in that lines with a high pH evinced an excess of males while the reverse applied with a low blood pH. Weir [11] subsequently showed that this divergence from parity was due to the male; differences in the female blood pH seemed to exert no influence. If this influence confined to the male were related to the heterogametic nature of the male mammal, then it would be logical to expect that the heterogametic female parent in fowl would show a similar controlling effect through blood pH differences, and that a below-average blood pH with the pullet or hen would result in an excess of female progeny. It might be superficially concluded that high and continued laying would lead to this condition through the withdrawal of calcium, but in fact with fowl there is an increase in blood calcium just prior to and coincident with ovulation [12]. It is true that there is usually a decline after the spring flush and it may be that this change exerts some influence on the sex ratio towards the close of the pullet year. McWhirter also refers to the effect of the diet in influencing pH and so the sex ratio. From previous work of the author, already cited [6], rations promoting a lower pH in the alimentary tract of the pullet did seem to be associated with a slight increase of females at the primary stage. Although in 1955 the primary sex ratio of the experimental flock was 45·4 per cent. males, there were small variations among the four groups of birds into which the flock was subdivided. The two groups receiving fishmeal manifested fewer females at the primary stage than the two groups receiving protein from vegetable sources, although an excess of females over males was evinced in all four groups. The details are shown in Table 7 although the differences are probably insignificant.

It may well be, however, that the assumption that any influence

arising from differences in the blood pH is associated with the male in mammals (or the female in fowl) by virtue of that being the heterogametic sex, is groundless. It may be that the apparent degree of control over the sex ratio exerted through blood pH differences arises from a condition of,

TABLE 7. *Primary Sex Ratio shown by Subdivisions of a White Leghorn Flock receiving Different Rations*

Group	*Basic ration*	*Primary sex ratio* % *males*
A	Grain and vegetable protein	45·9
B	,, ,, ,,	43·1
C	Grain and fishmeal	46·6
D	,, ,,	46·3
	Flock average	45·4

N.B. Rations A and B are assumed to lead to a lower pH in the alimentary tract than rations C and D.

or affecting, the sperm and, therefore, relates to the male with both mammals and fowl. This suggestion gains some support from the work of Popiel and Sikorowicz [13]. They found that with cocks fed an 'alkaline' ration mated with hens given an 'acid' ration, an excess of males was produced, but when the males were fed an 'acid' ration and the hens an 'alkaline' ration diet the reverse applied. In this experiment it would appear that the pattern is identical with that shown by mammals and that the differential sex ratio is caused by some condition of the sperm which is in turn related to or reflected by the blood pH of the male parent. In that event the seasonal change in the primary sex ratio would seem to reflect a seasonal change in some characteristic of the male. As the second-year birds in this experiment were mated to cockerels, and as this is customary commercial practice, the apparent widening of the sex ratio found in this experiment and elsewhere with laying continued into the second year cannot be attributed solely to a seasonal change in some condition of the male. It would seem that both sexes may contribute towards the condition, but in what manner is not apparent. The narrowing of the sex ratio here observed with cross-mating would give some support to the view that the male is largely responsible for differences in the sex ratio and it may be that the two breeds employed, viz. Brown and White Leghorns, differed in some blood condition. This suggestion is not very convincing as the evidence from the hatcheries suggests that narrowing of the sex ratio is a common feature with cross-mating as opposed to pure-mating.

The incidence of mortality among embryos from pure or cross-matings appears to follow the pattern expected for the heterogametic sex—with the marked exception that the tendency of the female (the heterogametic sex) to die more easily than the male is not apparent post-natally. Byerly and Jull [3] tentatively ascribed any differential mortality to sex-linked genes which impair viability. Both Lenz [14] and Huxley [4] propounded the hypothesis that with mammals (where the

male is the heterogametic sex) recessive sex-linked factors, with a slightly deleterious effect upon viability, accounted for the greater mortality among males. Huxley further considered that male children of wide racial crosses showed a greater survival rate pre-natally and after birth than the male offspring of parents both of the same race. This he attributed to heterosis which enabled the human male to resist the deleterious affect of harmful sex-limited factors. In this experiment the female—analogous to the male with mammals—has shown similar tendencies. The offspring of crosses between the two inbred lines of different breeds evinced a much reduced tendency for more females than males to die pre-natally under the stress arising during incubation. (With the cross-mated hens the death rate among the female embryos was low, but the male death rate remarkably low. But relatively few hens were tested and with the larger number of pullets cross-mated the reduction in the differential mortality compared with the offspring of pullets mated pure was clear cut.) But the analogy with the mammal breaks down in the post-natal period, for no differential sex mortality has been apparent after hatching in the 1956 season or in preceeding years. The same finding is reported by Byerly and Jull, although Landauer and Landauer [15] found a higher mortality among the male chicks up to 8 weeks of age in the flock under their supervision. There appears to be no obvious explanation why the female should not follow the expected mortality pattern of the heterogametic sex after hatching. The failure to do so must cast some doubt on the hypothesis that the higher female pre-natal mortality is simply related to sex-linked genes.

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A MANURIAL TRIAL RELATING TO BANDING DISEASE OF SISAL

G. W. LOCK

(*Sisal Research Station, Mlingano, Tanganyika*)

WITH PLATE 2

Summary

'Banding disease' of sisal is due to a deficiency of potassium. In a manurial trial on potassium-deficient land responses to nitrogen and phosphorus were not significant but applying 1,100 lb. of potassium fertilizer per hectare over the first five years of the life-cycle of the sisal resulted in an increase of 63 per cent. in fibre yields.

Potassium manuring had no effect upon the rate of leaf production or the number of leaves grown per plant before 'poling' or flowering, but the size and character of the leaf, particularly during the later stages of the experiment, were greatly improved and the healthy sisal yielded more fibre of higher quality than that suffering from banding disease.

Calculations show that the cost of the fertilizer may be recovered through the reduction in harvesting expenses per ton of fibre produced, besides enhancing the value of the crop obtained.

POTASSIUM-deficiency symptoms of sisal (*Agave sisalana* Perrine) are generally known as 'banding disease' in East Africa. This name was first given by Wallace [1] because it is descriptive of the bands of necrotic tissue which develop at the 'neck' or narrowest part of the basal half of the leaf. By all accounts 'leaf foot disease' of sisal in Indonesia [2] and 'leaf base disease' in Brazil [3] are synonymous with banding disease.

When Wallace was investigating an occurrence of the disease on an estate along the Central Line railway in Tanganyika during 1929 he transplanted some of the affected plants to fresh soil (a red earth derived from mica-bearing gneiss) at Morogoro. In due course all the new leaves were free of any symptoms and the plants grew normally. It was concluded, therefore, that banding disease was attributable to a soil deficiency rather than a pathogen, especially as one could not be isolated from the diseased tissue.

It has been shown in Java [4], Tanganyika [5], and Brazil [3] that banding disease is due to a shortage of potassium. One worker [6] ascribed the disease to a deficiency of magnesium, but this finding was based upon pot-culture work and it has not yet been confirmed by similar experiments carried out at the Sisal Research Station, Mlingano, Tanganyika [7]. The necrotic spots which develop in the basal part of the leaf as a result of a lack of magnesium differ from those due to a lack of potassium.

Description of the Symptoms

The signs of incipient potassium deficiency in sisal are small pale green and brownish-yellow spots, about 1–2 mm. in diameter, which develop on the underside of the leaf either at the neck or else on the bulbous base or 'butt end' of the leaf where it is attached to the stem

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(Fig. 1, Plate 2). Sometimes this is accompanied by a general paleness or chlorosis of the leaf bases. Later on these spots appear on both sides of the leaf and become necrotic, turning to a dark-brown mahogany colour, the affected areas spreading until they coalesce to form large irregularly shaped sunken patches of dead shrunken tissue. In the advanced stage the necrotic lesions spread right across the leaf forming a broad band 10–15 cm. wide. This causes the leaf to collapse at its narrowest part, the movement of sap ceases, and before long the distal end of the leaf turns yellow, then purplish pink, later curling up and withering (Fig. 2, Plate 2). The resultant loss of leaf area has a marked effect upon the size of new leaves which gradually become shorter and less heavy, while the actual content of fibre (not the percentage of fibre) is reduced. The entire plant has a spindly appearance or becomes stunted and in extreme cases the central spike may rot away and the plant is unable to produce an inflorescence or 'pole' at the end of its life-cycle.

In sisal much of the potassium occurs in the leaf juices [4, 8], and it can be easily translocated within the plant. Thus when the potassium supply is barely sufficient or at a low level, the plant draws upon the potassium contained in the lowest and oldest leaves for building up new leaves inside the central spike or growing point. Analyses of transverse leaf sections carried out by Diekmahns [7] showed that the concentration of potassium was normally lowest in the neck of the leaf where the symptoms of banding disease are most liable to arise, and in diseased leaves potassium may be completely absent in this part of the leaf.

Occurrence of the Disease in East Africa

Although banding disease has been known in Tanganyika for many years, it is only within comparatively recent times that it has become more widespread. This is undoubtedly a consequence of growing sisal continuously on the same land without manuring. In plantations banding disease usually begins by appearing in small localized and irregular patches of about a quarter to one hectare in extent; eventually these may become larger and a considerable area amounting to 100 hectares or more per estate may be affected.

Banding disease has been noted in sisal on Red Earths overlying coral rock, red Latosols derived from gneiss (particularly on hill crests), poor acidic red sands, fertile loams, and blackish-grey clays in bottom lands. It has not yet been observed in Tanganyika on rich alluvial soils having a high mica content or soils of recent volcanic origin, although it has developed on a red volcanic earth in the Kenya Highlands not far from Thika. In Tanganyika banding disease is most common in the Tanga district but it is not unknown in the sisal-growing localities of the Southern Province and it also occurs to a very limited extent on a few estates near Dar-es-Salaam.

Banding-disease symptoms have been recorded on small bulbil plants growing in nurseries on red soils, especially after manuring with sisal waste. It has also been seen in young sisal less than one year old if the soil happens to be exceptionally low in potassium. Sometimes young sisal may grow perfectly healthily until it is three or four years old, and

thereafter the disease may appear with unusual rapidity, commonly after a flush of growth. In the latter instance the upright leaves surrounding the central spike frequently suffer most, the lesions develop quickly, are purplish black, and have a waxy bloom. There is also considerable exudation of globules of gum on the surface of the leaf.

Analyses of soils where banding disease is prevalent, made by Leutenegger [9], indicate that deficiency symptoms are liable to arise if the exchangeable potassium content of the soils falls below 0·2 m.e. per cent. (extraction with N ammonium acetate). This is not an invariable rule since it appears that the nitrogen status of the soil may be another factor controlling the incidence of the disease. In certain manurial trials carried out by the Sisal Research Station on outside estates, dressings of ammonium sulphate have been known to make the symptoms worse. On the other hand, sisal which is weakly, due to growing on poor soil with an exceptionally low nitrogen content, often does not show the disease.

A Manurial Trial on Potassium-deficient Land

The main purpose of this paper is to describe a manurial trial carried out by the Sisal Research Station on a plantation in the Tanga district. The trial, which lasted for seven years, was sited on an area of less than 1 hectare where the previous crop of sisal had suffered severely from banding disease. The final results not only confirm that this disease may be rectified by applying potassium fertilizers, but they also show that such treatment would be highly economic.

The experiment was based on a $3 \times 2 \times 2$ factorial design of Yates [10]. Originally it was put down as one of a territory-wide series of manurial trials to test the value of sodaphosphate (made by the East Africa Industrial Research Board, Nairobi, from local deposits in Uganda) as a phosphorus fertilizer for various crops in East Africa. Thus the treatments comprise three levels of sodaphosphate applied in the presence and absence of nitrogen and of potassium. Only the potassium treatment affected the yields of sisal fibre on this particular soil type.

Soil and climatic conditions. The soil is a fairly deep brownish-red loam, freely draining, nearly neutral in reaction, derived from gneiss parent rocks at the foot of the escarpment of the eastern Usambara mountain massif. As far as is known it has been cultivated for the past forty to fifty years mainly under sisal. The annual rainfall of the district is about 50 inches, with a bi-modal distribution, the main rains falling in May and the small rains about October or November. These ecological conditions are definitely favourable for sisal.

Preparation of land and planting. Disease symptoms on the former crop of sisal provided a useful indication of soil conditions and helped in the demarcation of the trial on an area where the soil was likely to be most deficient. After cutting out and carrying off the remnants of the previous cycle of sisal, the land was weeded and cultivated with a rotary cultivator. Healthy sisal plants raised from bulbils in nurseries at the Sisal Research Station were planted in April 1947 and a double-row system of spacing, $4 \times 1 \times 0{\cdot}80$ m. was adopted. This spacing gives a

plant population of 5,000 per hectare which is common on many estates in Tanganyika. The size of each plot was 12·80 × 10 m. and the internal plot contained twenty-four recorded plants.

Growth measurements were taken after the trial had been established for one year and thereafter at regular intervals of two months. New leaves are easily marked and counted by snipping off part of the tip thorn with a pair of secateurs. The last unfurled leaf next to the central spike was used for measuring leaf length on each occasion.

Applications of Fertilizers

Amount of fertilizers applied prior to fourth cutting in 1952

Fertilizer	*Year of application*					*Total*
	1947	*1948*	*1949*	*1950*	*1951*	
p_1 Sodaphosphate .	5	5	5	5	5	25 cwt./ha.
p_2 Sodaphosphate .	10	10	10	10	10	50 ,,
n Ammonium sulphate.	2½	2½	2½	2½	2½	12½ ,,
k Potash fertilizer .	100[a]	200[a]	300[a]	200[b]	300[b]	1,100 lb./ha.

a: Sulphate b: Muriate

All the fertilizers were broadcast by hand in a narrow band along the rows of sisal. The first application was made in June 1947, three months after planting, when the sisal had become well rooted, but in subsequent years the bulk of the fertilizers were given at the beginning of the main rains in April. The quantity of potassium fertilizer was increased to 200 lb. per hectare during 1948 in order to allow for the larger size of the plants. Afterwards this annual dressing was supplemented by an extra 100 lb. per hectare in October, in 1949 and again in 1951, so as to ward off early symptoms of banding disease which had begun to appear in some plots, indicating that the amount of potassium supplied had been insufficient in these years. After 1951 no symptoms were seen again in the plots receiving potassium and no further applications were required.

Symptoms of banding disease were not visible until February 1948, ten months after planting, when they developed rather suddenly in all the plots without potassium. Potassium manuring had no effect upon the number of leaves grown, or upon poling.

Cultivation methods. The double rows of sisal were weeded by hand six times during the first year, four times in the second, and thereafter immediately after cutting. Low grass and bush growth between the double rows was cutlassed once annually. Sisal-weevil (*Scyphophorus acupunctatus*) damage to transplants was not excessive and a full stand of uniform plants was obtained in the first year.

Harvesting. Cutting and decortication began in September 1950 when the sisal was nearly 2½ years old from planting out, and were repeated annually until the sisal poled out in July 1954. Twenty leaves per plant were left uncut at each cutting except the last. Besides counting the number of leaves removed from each plant, those from each plot were sorted into five grades according to the severity of the disease symptoms, as follows:

Grade 1. No lesions.
" 2. Incipient symptoms.
" 3. Severe lesions forming spots 5–10 cm. in diameter.
" 4. Lesions forming a band across the leaf but leaf not collapsed.
" 5. As for (4) but leaf collapsed and withering.

Leaf counts and leaf weights were obtained from each plot at each cutting but it was found necessary to bulk the leaves from each plot in order to simplify decortication. The latter operation was carried out on a standard machine in the estate factory. Fibre yields are based on the weight of sun-dried unbrushed fibre extracted and fibre lost in the waste leaf pulp was not recovered.

Experimental Results

Fibre yields. The final results of this experiment, expressed as total yields of fibre in tons per hectare, are set out in Table 1. The level of yields from the healthy plots is high.

TABLE 1. *Fibre Yields*

Tons (metric) per hectare

Treatments	p_0	p_1	p_2	*Mean*
Control . . .	10·1	13·4	13·2	12·2
n	10·9	10·9	14·8	12·2
k	20·6	19·9	19·2	19·9
nk . . .	20·2	20·0	19·8	20·0
	15·4	16·1	16·8	

Least significant difference (P = 0·05):

Within body of table		4·45	tons per ha.
Side means		2·57	" "
Means for p_0, p_1, or p_2		2·23	" "
Means of n_0	no nitrogen plots	16·1	" "
" n_1	nitrogen plots	16·1	" "
" k_0	no potash plots	12·2	" "
" k_1	potash plots	19·9	" "

Least significant difference between means (18 plots), (P = 0·001) = 3·35 tons per ha.

The above figures show that the only treatment which had any effect upon fibre yields was potassium manuring. Applying half a ton of potassium fertilizer per hectare over the first four years of the life-cycle of the sisal has resulted in a response of 7·7 tons of fibre per hectare, or an increase in yield of nearly 63 per cent. With sisal the benefits of manuring do not become very marked until the fourth or fifth cuttings when the heaviest crops are usually obtained, and this trend can be seen from Table 2.

Number of leaves. The total number of leaves obtained from the plots with and without potassium (432 plants in each case) which might have been available for cropping is set out in Table 3.

Table 3 shows that the total number of leaves cut per plant, whatever their condition, has not been affected by potassium manuring. Potassium

has, however, had an important effect upon the character of the leaf, which has resulted in twenty more leaves per plant suitable for decortication from the plots with potassium than from those without

TABLE 2. *Fibre Yields in Successive Cuttings—tons per hectare*

	Cutting	*No* K	K	*Response*
Aug. 1949 . . .	1st	0·60	1·25	0·65
Sept. 1950 . . .	2nd	1·86	2·58	0·72
Sept. 1951 . . .	3rd	2·11	3·19	1·08
Sept. 1952 . . .	4th	2·93	5·00	2·07
Aug. 1953 . . .	5th	2·72	4·58	1·86
July 1954 . . .	6th	2·00	3·36	1·36
Totals . . .		12·22	19·96	7·74

TABLE 3. *Total Numbers of Leaves cut*

	No K	K
Leaves weighed and decorticated .	74,084	82,769
Leaves weighed but discarded .	11,629	3,192
Leaves withered and not weighed .	759	79
Totals	86,472	86,040
Mean no. of leaves per plant . . .	200	199
Mean no. of leaves decorticated per plant. .	172	192

potassium. It is estimated that this effect alone would account for nearly 2 tons of the increase in yield of fibre due to manuring.

Weight of leaf. The weight of leaf cut from the plots with and without potassium is given in Table 4:

TABLE 4. *Total Weight of Leaf Cut* (*kilogrammes*)

	No K	K
Leaf decorticated . . .	27,991	42,608
Leaf discarded	2,413	973
Totals	30,404	43,581

The influence of potassium in increasing the size and weight of leaf yielded can be seen in Table 4. It is clear that a great part of the response in fibre yield was due to larger leaves of better quality having been obtained from the plants given potassium.

Severity of symptoms. At each cutting the leaves from each plant were sorted into five grades according to the severity of the lesions as described earlier (p. 223). Leaf in grade 5 was rejected because it was unfit for decortication. Also, at the first cutting only, that in grade 4 was rejected owing to its low value; but it was decided to decorticate this class of leaf from subsequent cuttings since it contained undergrade fibre which was not entirely unmarketable. It might be argued that the rejection of

grade-4 leaf from the first cutting had artificially enhanced the response to potassium, but even if this were so the effect would be only of the order of 0·18 ton per ha.

Classification of the number of leaves decorticated according to severity of symptoms is shown in Table 5.

TABLE 5. *Number of Leaves Decorticated, classified according to severity of symptoms*

Grade	*1. None*	*2. Slight*	*3. Mild*	*4. Severe*	*Total*
No-potassium plots					
1st cutting . .	264	3,040	6,225	. .	9,529
2nd ,, . .	240	8,026	4,681	1,810	14,757
3rd ,, . .	1,173	4,703	3,547	3,039	12,462
4th ,, . .	592	6,007	6,427	1,701	14,727
5th ,, . .	4,333	5,467	1,913	773	12,486
6th ,, . .	4,530	3,947	1,524	122	10,123
Total . . .	11,132	31,190	24,317	7,445	74,084
Per cent. . .	15·0	42·1	32·8	10·1	100·0
Potassium plots					
1st cutting . .	2,737	6,130	5,840	. .	14,707
2nd ,, . .	6,442	7,807	900	25	15,174
3rd ,, . .	8,649	2,870	601	113	12,233
4th ,, . .	8,803	6,370	819	54	16,046
5th ,, . .	10,282	3,034	55	0	13,371
6th ,, . .	9,502	1,631	105	0	11,238
Total . . .	46,415	27,842	8,320	192	82,769
Per cent. . .	56·1	33·6	10·1	0·2	100·0

Nearly 90 per cent. of the leaves from the potassium plots were classified under grades 1 and 2, which yielded clean or very slightly blemished fibre, whereas almost half of the crop from the no-potassium plots with mild or severe banding disease (grades 3 and 4) was quite seriously stained or blemished, which lowers its value.

The weight of leaf harvested under each leaf grade is shown in Table 6.

The disparity between the two treatments is greater in respect of weight of leaf decorticated than for the number of leaves decorticated (Table 5). This was due to the poor quality of the leaf, as shown in Tables 7 and 8.

Normally sisal leaves become heavier and contain more fibre as the plant gets older, and these trends can be seen quite clearly in the data for the potassium plots, but they are much less pronounced in the case of the plots without potassium and they may disappear if the banding disease symptoms are severe.

Economic considerations. The number of leaves required to produce a ton of fibre has a direct bearing upon cutting costs since the usual task for a sisal cutter in Tanganyika is 2,100 leaves. It can be calculated that 19·9 tons of fibre obtained from the potassium plots would entail about 961,300 leaves, or the equivalent of 458 tasks, whereas similar figures for the plots without potassium, which yielded 12·2 tons of fibre, would be

TABLE 6. *Weights of Leaf Harvested, classified according to severity of symptoms (kilogrammes)*

Grade	*1. None*	*2. Slight*	*3. Mild*	*4. Severe*	*Total*
No-potassium plots					
1st cutting . .	64	883	1,637	..	2,584
2nd ,, . .	115	3,144	1,652	633	5,544
3rd ,, . .	494	1,823	1,343	1,182	4,842
4th ,, . .	327	2,533	2,496	572	5,928
5th ,, . .	1,952	2,223	726	276	5,177
6th ,, . .	1,749	1,564	571	32	3,916
Total weight . .	4,701	12,170	8,425	2,695	27,991
Per cent. . .	16·8	43·5	30·0	9·7	100·0
Potassium plots					
1st cutting . .	822	2,102	1,917	..	4,841
2nd ,, . .	3,189	3,705	425	8	7,327
3rd ,, . .	4,641	1,570	338	58	6,607
4th ,, . .	5,335	3,804	460	25	9,624
5th ,, . .	6,294	1,730	36	0	8,060
6th ,, . .	5,199	899	53	0	6,151
Total weight . .	25,480	13,810	3,229	91	42,610
Per cent. . .	59·8	32·4	7·6	0·2	100·0

TABLE 7. *Mean Weights per Leaf, with and without Potassium, classified according to severity of symptoms, gm.*

	Grade 1, Free		*Grade 2, Slight*		*Grade 3, Mild*		*Grade 4, Severe*		*Mean*	
Cutting	*No* K	K	*No* K	K	*No* K	K	*No* K	K	*No* K	K
1st	244	300	291	343	263	328	..	..	271	329
2nd	477	495	392	475	353	472	350	320	376	483
3rd	421	537	388	547	379	560	389	516	389	540
4th	553	606	422	597	388	561	336	461	403	600
5th	451	612	407	570	379	645	358	..	415	603
6th	392	565	398	570	375	501	249	..	390	565
Mean	422	549	390	496	346	388	362	475	378	515

TABLE 8. *Fibre Content of Leaves, with and without Potassium*

	Mean wt. of fibre per leaf in gm.		*Fibre percentage*		*No. of leaves per 1 ton of fibre*	
Cutting	*No* K	K	*No* K	K	*No* K	K
1st	5·5	7·3	2·01	2·23	183,486	136,426
2nd	10·9	14·7	2·90	3·04	91,912	68,027
3rd	14·7	22·5	3·77	4·17	68,213	44,444
4th	17·2	26·9	4·27	4·49	58,140	37,174
5th	18·8	29·6	4·53	4·91	53,220	33,807
6th	17·0	26·2	4·37	4·63	58,685	39,197
Mean	14·3	20·8	3·77	4·07	70,175	48,008

859,000 leaves, or 409 tasks. Cutting-labour costs about 3 shillings per task and on this basis cutting the good leaf would cost 69·04 shillings per ton of fibre compared with 100·57 shillings per ton of fibre for the poor leaf. Potassium manuring, therefore, could effect a saving of 31·53 shillings per ton of fibre produced or nearly twice the cost of the potassium fertilizer used, which works out at almost 17 shillings per ton of fibre, or 338 shillings per hectare (excluding costs of application).

The fibre obtained from the four grades of leaf could have been graded into No. 1, A, 3Long, and Undergrade respectively, and if the crop obtained is valued according to current prices for these grades of sisal, the extra return due to higher quality of fibre can be assessed.

TABLE 9. *Valuation of Sisal Crop per hectare*

Grade	*Price per ton*	*No potassium*		*Potassium*	
		tons	*value*	*tons*	*value*
	£		£		£
No. 1	75	2·05	153·75	11·93	894·75
A	74	5·31	392·94	6·47	478·78
3L	73	3·68	268·64	1·51	110·23
U.G.	70	1·18	82·60	0·05	3·50
		12·22	£897·93	19·96	£1,487·26
		Av. value per ton	£73·48		£74·51

The calculated difference in gross return as a result of correcting banding disease by the use of potassium fertilizers is £589·33 per hectare, while the average value of the crop is raised by about £1 per ton. The latter figure alone more than covers the cost of the potassic manuring, without taking into account the extra crop obtained. The proportions of grades of fibre have been calculated according to the leaf weights for each grade of leaves. If the increase in crop due to potassium is ignored and the yield of the no-potassium plots is taken instead, but the grades used in the calculation are those obtained from the sisal grown with potassium fertilizer, the gross value of the crop from the no-potassium plots is raised from £897·93 to £910·55, or an increase of £12·62 per hectare. This sum alone would go far towards paying for the cost of the fertilizer.

The cost of growing the extra crop of leaf may also be calculated as 35·71 shillings per ton of extra fibre obtained and such a figure is well below the cost of growing leaf in the ordinary way without manuring.

The results of this experiment demonstrate with reasonable certainty that it is economic to treat potassium-deficient sisal land with potassium fertilizers, and many sisal estates in Tanganyika are now using such fertilizers as a matter of routine.

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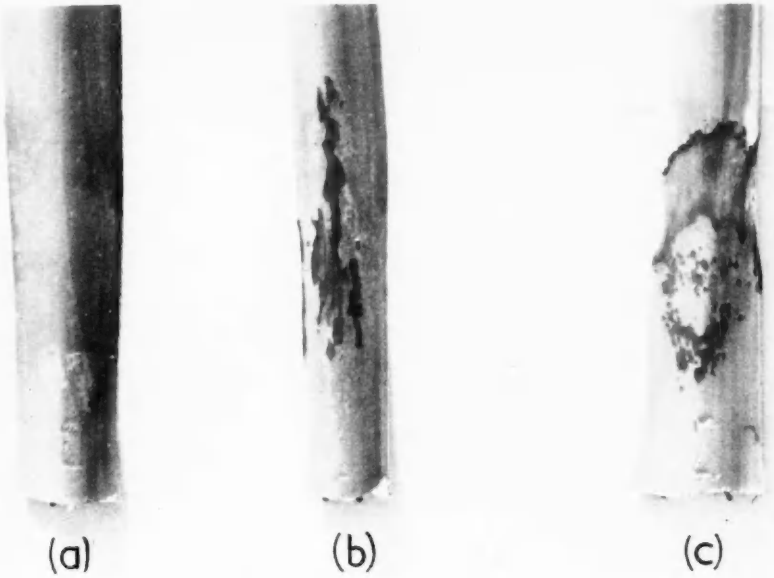

FIG. 1. 'Banding disease' of sisal
(a) Pale yellow spots or incipient symptoms
(b) More advanced stage showing necrotic lesions
(c) Band of lesions leading to collapse of leaf

FIG. 2. View of a sisal plant showing potassium deficiency symptoms. The leaves curl up and wither after collapsing in the basal region

ENVIRONMENTAL AND HEREDITARY EFFECTS ON CALVING INTERVALS IN MILKING BUFFALO IN EGYPT

K. A. ALIM[1]

(*Faculty of Agriculture, Alexandria University, Egypt*)

Summary

Data were collected on 593 milking buffalo having 2,344 calving intervals completed during the years 1928–52 in a dairy herd near Alexandria.

The mean interval between births was 552±3·5 days and the average number of calving intervals per cow was 3·95±0·10.

The analysis of the components of variance indicated the relative importance of years, months of calving, and calving sequence in determining the interval between births. Years, months, and sequences contributed 2·69, 2·16, and 1·67 per cent. respectively to the total variance.

The average age of the cows at calving was 7·0±0·03 years and the average age at first calving was 3·1±0·04 years.

The repeatability of calving-interval single records based on 492 cows having 2,243 records[2] was 0·179±0·023. The average estimate obtained for the first three consecutive records and for intervals separated by one and two records were 0·181±0·056, 0·148±0·063, and −0·001±0·076 respectively. Intra-cow correlations of 0·162±0·034 and 0·126±0·032 were calculated from two groups of data for cows having from two to five records and from six to eleven records.

The prediction of the future records of a cow was improved when the average of two or of three records was used.

The heritability of the calving-interval single records was of the order of 0·130±0·134–0·076±0·156. Similar estimates obtained for longevity indicated no hereditary differences between cows in this respect.

In Egypt, the reproductive efficiency of the milking buffalo, as measured by calving intervals, has been reported to be very low [1]. Calving at intervals longer than optimum limits the increase in the population number and causes a serious economic loss to the dairy farmer as it reduces the average reproductive life of the animals. An increase in the productive herd-life of the animals should help to maintain higher production and will also lower the cost of milk production by reducing the cost of herd replacements.

In order to shorten and regulate the calving interval, it is necessary to know how it is influenced by different environmental factors, and its relationship with other traits of economic importance. Estimates of repeatability for the character give the best selection procedures, and heritability values help to determine an efficient breeding system and aid in measuring the effect which selection may have on this trait. This study is an attempt to present data on certain measurable non-genetic factors which affect the interval between births, and to estimate the repeatability and the heritability of this trait.

The dairy herd used in this investigation is situated on the north of the Delta 55 kilometres east of Alexandria in lat. 30° 20′ N., long.

[1] Present address: Department of Animal Production, Ministry of Animal Resources, Khartoum, Sudan.

[2] 'Calving-interval records': for brevity the word 'record' is used throughout this paper to mean a *recorded interval between consecutive calvings.—Editor.*

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30° 30′ W. The average annual rainfall is 165 mm. and most of the rain falls during winter. The herd was founded in 1928 and all normal calving-interval records completed in the herd until 1952 inclusive were studied. Hand-mating was practised and the cows suckled their young for 38±0·57 (1,022) days (mean±standard error, with number of observations), after which they were milked twice daily and every milking was weighed. A total of 2,344 calving-interval records were obtained on 593 buffalo cows, made over 25 years. The average number of calving intervals per buffalo cow was 3·95±0·10.

The records were classified according to years, months, lengths, and lactation numbers. The statistical analysis used was as outlined by Snedecor [2].

Results and Discussion

Sex-ratio. The data on sex-ratio were obtained on 1,370 calves born from 1929 to 1950 inclusive, of which 715 were males and 655 females. The males were 52·19±1·41 per cent. of the total. A homogeneity test applied to the data showed that certain years had an apparent influence

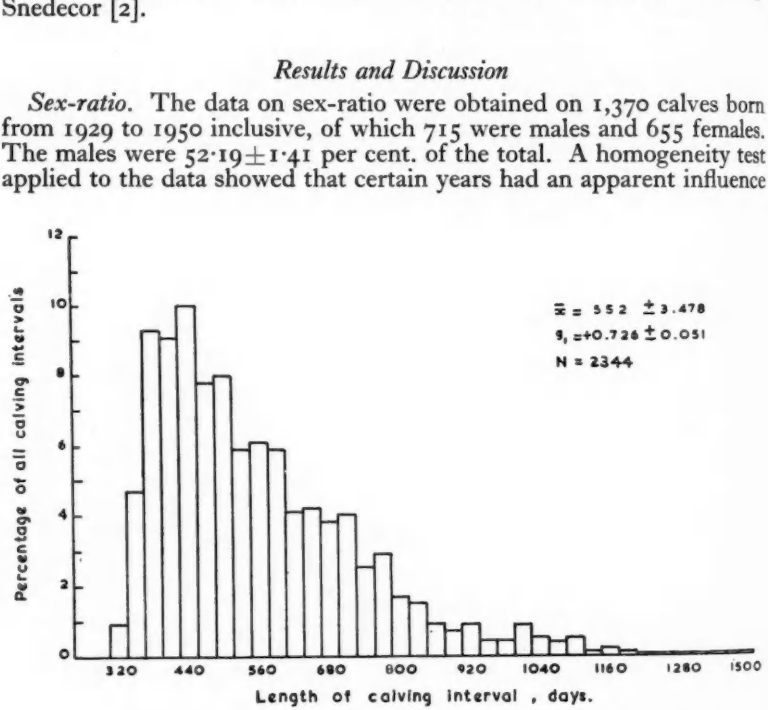

FIG. 1. Frequency distribution of all calving intervals in different lactations.

on sex in the various groups. Such influence was not shared by other groups in different years ($\chi^2 = 12{\cdot}65$; for P = 0·05, $\chi^2 = 9{\cdot}49$, D.F. 4). Although there were some variations, neither the month of calving nor the number of lactations had any significant effect on the sex of the offspring.

Frequency distribution. In this part of the work, the whole of the 2,344 records were analysed and the results are presented graphically in

Fig. 1. The distribution of the data is positively skewed; the mean and median are $552 \pm 3{\cdot}48$ and $440 \pm 4{\cdot}35$ days respectively. The measure of the skewness (g) is $0{\cdot}73 \pm 0{\cdot}05$, which is highly significant.

Variation between years. All the records were arranged in groups according to the calendar years in which they started. The differences between the average length in each group and the mean for the whole population have been obtained in terms of σ-units, calculated within years. The results are shown in Fig. 2.

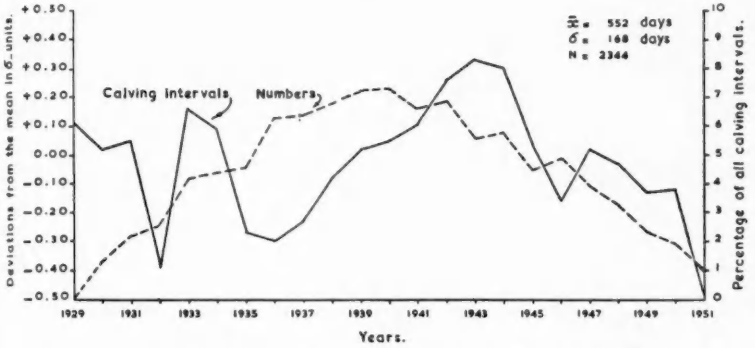

FIG. 2. Average lengths and numbers of calving intervals in the different years.

It is evident that there are variations in the calving intervals between years. However, such fluctuations are greatly associated with changes in the level of herd management, amount and quality of feed supply, atmospheric conditions, disease incidence, and genetic and age composition of the population.

The analysis of variance showed that differences between years were highly significant. The proportion of the total variance which was due to these differences amounted to 2·69 per cent.

Variation between months (Table 1). Month of calving is highly associated with the length of the preceding calving interval. This is attributed to the lower conception rate of the buffalo cows during summer and early autumn [1]. Analysis of variance of all the calving intervals, according to their terminal months, revealed highly significant variations between months. The proportion of the total variance which was due to this source of variation was 2·16 per cent.

However, buffalo cows that calve down in this area between October and January fit their demands to the feed supply; there is an abundance of berseem (*Trifolium alexandrinum*) during winter and until early summer and a shortage at other times of the year particularly during most of the summer and early autumn. Milk production based largely on that green feed is very profitable as it is plentiful and produced at a much lower cost per gallon.

The level of production of cows of shorter calving intervals is likely to follow the growth curve of the berseem. Moreover, the proportion

of the cows that calve during the favourable months tends to decrease as the length of the preceding calving interval increases.

TABLE 1. *Effect of Preceding Calving Interval on Month of Calving (all intervals beyond 20 months were omitted)*

Month of calving	Calving intervals		Length of calving interval (months), and no. of records				
	No.	%	11 and 12 129	13 and 14 407	15 and 16 452	17 and 18 322	19 and 20 269
			per cent. of year's total				
Jan.	173	10·9	15·4	13·5	12·2	8·4	5·9
Feb.	155	9·8	6·2	10·3	12·2	9·3	7·4
Mar.	154	9·7	7·8	8·4	10·4	12·4	8·6
Apr.	88	5·6	1·6	4·9	6·4	6·5	5·9
May	79	5·0	3·1	3·4	3·9	7·8	6·7
June	61	3·9	1·6	0·7	4·6	6·2	5·6
July	63	4·0	0·8	1·0	2·9	6·5	8·9
Aug.	102	6·5	3·9	5·2	3·9	7·8	12·3
Sept.	154	9·7	13·2	7·6	7·7	12·4	11·5
Oct.	170	10·8	17·1	14·0	7·3	8·7	11·2
Nov.	177	11·2	16·3	14·3	12·2	4·1	11·2
Dec.	203	12·9	13·1	16·7	16·3	9·9	4·8
Totals	1,579	100·0	100·0	100·0	100·0	100·0	100·0

Variation between sequences. The influence of calving sequence on interval between births was obtained from the records for the first four successive calvings (Table 2).

TABLE 2. *Means, Standard Deviations, and Coefficients of Variation of the First Four Calving Intervals*

Lactations	No. of records	Calving intervals		
		Mean	Standard deviation	Coefficient of variation
		(days)	±	
1st . . .	348	618	180	29·1
2nd . .	397	565	164	29·0
3rd . . .	350	562	179	31·9
4th . . .	278	551	175	32·2
Total or mean .	1,371	575	174	30·4

The analysis of variance indicated that variations in the calving interval with time, as shown by the calving sequence, were highly significant. These variations accounted for 1·67 per cent. of the total variance and were mainly due to the first record. This could not be attributed to culling of animals having longer calving intervals, as variations within lactations between the non-culls and all the animals are negligible in this respect.

The variance contributed by sequences is not related to the age of buffalo cows at first calving, since the latter was not significantly correlated with the first-calving interval. The correlation coefficient obtained from these data was $r = 0{\cdot}001 \pm 0{\cdot}06$ (252 D.F.).

The coefficient of variation of the calving interval tends to increase from early to later records. The amount of increase is more noticeable between the second and the third record. However, the average estimate for this coefficient is rather too high to provide wide scope for rapid development.

Age at calving. Means and standard deviations for age at calving are given in Table 3.

TABLE 3. *Means and Standard Deviations for Age of Buffalo Cows at Different Lactations*

Lactation numbers	*Number of observations*	*Age at calving*	
		Mean	*Std. dev.* ±
		(*yr.–mo.*)	(*mo.*)
1st	297	3–1·6	7·6
2nd	254	4–9·8	9·6
3rd	224	6–4·7	11·2
4th	181	8–0·6	15·1
5th	130	9–5·3	20·9
6th	86	10–8·5	17·6
7th	62	12–0·3	19·1
8th	47	13–3·5	17·5
9th and over	46	14–5·9	17·4
Total or mean	1,327	6–11·7	12·8

TABLE 4. *Analysis of Variance of Calving Intervals in Buffalo Cows*
(*Calving interval measured in one-tenth-day units*)

Source of variation	*D.F.*	*Mean square*
Total	2,242	..
Between cows and years	491	501
Between years	19	1,055
Between cows within years	472	478
Error	1,751	239

Components of variance and repeatability

$\sigma^2 c$	52·414
$\sigma^2 e$	239·057
r	0·179
n^a	4·566

[a] Average number of records per cow.

The average age of the cows at first calving was 37·6±0·4 months and thereafter age tended to increase by nearly 20 months for each subsequent calving until the fourth. After the fourth calving, increase in age between consecutive calvings declined from 16 to 14 months.

Similar results obtained by Johansson [3] showed that the Red and White cattle in Sweden calved for the first time at about 34 months and that age increased by nearly 13 months for each following calving.

Repeatability of calving interval. The repeatability [4] of the single

records for the calving-interval length was determined by the intra-class-correlation technique, $r = \sigma^2c/(\sigma^2c+\sigma^2e)$. The component of variance σ^2c results from hereditary differences and permanent environmental influences peculiar to each individual. The component σ^2e is the variance among records of the same animal and is assumed to be random from one record to another.

The computations have been made within years to minimize the influence of time trend in herd management. The results show that the correlation between the calving intervals of the same buffalo cow in different lactations was reduced in this way by 2 per cent. They also indicate that there were highly significant variations between buffalo cows. Table 4 contains the analysis of variance, the components of variance, and the estimate of repeatability.

The repeatability estimate reached on part of the same data (cf. [1]) was 0·15 (537 D.F.). Legates [5], however, studied the length of calving interval among herds in North Carolina and found an intra-cow repeatability of $0{\cdot}133 \pm 0{\cdot}026$. Ashfaq and Mason [6], Johansson and Hansson [3], and Mahadevan [7] reported estimates which are not significantly different from zero.

The repeatability values for consecutive and non-consecutive calving intervals in the first four calvings are given in Table 5.

TABLE 5. *Repeatability between Consecutive and Non-consecutive Calving Intervals*

Lactations compared	*No. of pairs*	*Correlation coefficients*
1st and 2nd . . .	280	$0{\cdot}125 \pm 0{\cdot}059$
2nd and 3rd . . .	330	$0{\cdot}231 \pm 0{\cdot}052$
3rd and 4th . . .	275	$0{\cdot}178 \pm 0{\cdot}058$
Total and mean . .	885	$0{\cdot}181 \pm 0{\cdot}056$
1st and 3rd . . .	221	$0{\cdot}121 \pm 0{\cdot}066$
2nd and 4th . . .	260	$0{\cdot}170 \pm 0{\cdot}061$
Total and mean . .	481	$0{\cdot}148 \pm 0{\cdot}063$
1st and 4th . . .	174	$-0{\cdot}001 \pm 0{\cdot}076$
All records . . .	1,540	$0{\cdot}149 \pm 0{\cdot}060$

There is a slight tendency for the second, third, and fourth records of the same cow to be more alike, as compared to her first record. The estimate diminished until it might be taken to be zero as the period of time between the records compared increased. The decrease in repeatability with time may have been due to the semi-permanent fraction of the total variance which is subject to variations between the records of the same cow.

The selection of only those cows having a larger number of records would also reduce the between-cow variability and this would reduce the repeatability value. Thus, a study of calving intervals involving 343 buffalo cows having two to five records, and 149 buffalo cows having from six to eleven records (Table 6) indicated that there are appreciable differences between the repeatability of the single calving-interval records in the two groups of data studied. The repeatability decreased

as the number of records of a buffalo cow increased. The estimates obtained were $0{\cdot}162 \pm 0{\cdot}034$ and $0{\cdot}126 \pm 0{\cdot}032$ respectively. It is probable therefore that the prediction of the future calving intervals is better based on consideration of more than one record.

TABLE 6. *Means and Standard Deviations in Calving Intervals for Cows with Two to Five and with Six to Eleven Records*

Groups	*Average no. of records*	*Calving intervals (days)*	
		Mean	*Std. dev.±*
Cows with 2–5 records . .	$3{\cdot}33 \pm 0{\cdot}06$	588	168
,, 6–11 ,, . .	$7{\cdot}38 \pm 0{\cdot}11$	520	142

The study of the extent to which the inclusion of two and three calving-interval records would improve the information about the individual's rate-of-calving ability was based on 301 buffalo cows possessing records for their first available four calving-intervals. The composition of mean square indicated a repeatability estimate of $0{\cdot}120 \pm 0{\cdot}033$ for the single records in this selected group. Repeatability estimates calculated for the average of the first two and first three records compared with the third and the fourth record respectively amounted to $0{\cdot}152 \pm 0{\cdot}056$ and $0{\cdot}172 \pm 0{\cdot}055$ respectively. By comparing the average of the first two records with the average of the subsequent two records the repeatability estimate came to $0{\cdot}177 \pm 0{\cdot}055$.

Daughter-dam comparisons. Table 7 shows means, standard deviations, and coefficients of variation for age of dams and daughters, and number of daughters per dam. The calculations were made on 178 dams and 250 daughters.

TABLE 7. *Means, Standard Deviations, and Coefficients of Variation for Age of Dams and Daughters and Number of Daughters per Dam*

Traits	*Mean*	*Standard deviation ±*	*Coefficient of variation*
Age of dams (no. of calvings) .	6·76	2·09	30·91
Age of daughters (no. of calvings)	4·58	2·57	56·11
Number of daughters per dam .	1·40	0·68	49·63

The difference of $2{\cdot}18 \pm 0{\cdot}22$ between the average number of apparently normal calvings of dams and daughters who completed their herd-life records was highly significant statistically ($P < 0{\cdot}01$). This difference is to be expected, since cows that started their life early in the history of the herd were kept longer, and they also left more daughters. However, longevity of buffalo cows in a herd is considerably affected by farm practice. It may indicate only part of the total productive life of the cows as some of the individuals culled from the herd may spend the rest of their lives with other farmers.

Employing the co-variance method, the correlation and regression of the longevity of daughters on dams were calculated within years. The proportion of dams that had only one, two, three, or four daughters were 69·7, 21·9, 6·7, and 1·7 per cent. respectively. When the dam had more than one daughter, the dam's record was repeated with the record of each daughter. The respective correlation and regression amounted to $-0{\cdot}058 \pm 0{\cdot}065$ and $-0{\cdot}080 \pm 0{\cdot}081$ respectively. This negative correlation and regression, although insignificant, suggests that the relationship between longevity of daughters and dams in the herd is of an environmental nature.

Applying the same method of analysis the relationship between the single calving intervals of 184 dams and 224 daughters was determined within years. Since the first freshening date was not known for all dams and daughters, the first two normal calving dates available were used to obtain the calving intervals of all the cows compared. The average length of calving intervals of dams and daughters were $523 \pm 9{\cdot}67$ and $574 \pm 9{\cdot}96$ days respectively. The differences between the records of these two groups were highly significant statistically. In the present analysis, the correlation and regression of daughters on dams was $0{\cdot}065 \pm 0{\cdot}067$ and $0{\cdot}038 \pm 0{\cdot}078$, and doubling these values will give estimates of $0{\cdot}130 \pm 0{\cdot}134$ and $0{\cdot}076 \pm 0{\cdot}156$ for the heritability of differences between these single records. These estimates are likely to contain some of environmental correlation between daughters and dams as the computations have not been made on an intra-sire basis.

These estimates of heritability agree with the other published value of 0·13 (17 D.F.) by Asker *et al.* [8]. In cattle, Dunbar and Henderson [9], Legates [5], and Brown *et al.* [10] showed that the heritability of the interval between calvings is zero. However, the low and insignificant estimates obtained in this study support the contention that variation in this measure of reproductive efficiency is determined mostly by environment.

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THE COMPOSITION AND AGRICULTURAL VALUE OF SOME GRASS SPECIES IN NIGERIA

V. A. OYENUGA

(*Division of Animal Nutrition, Faculty of Agriculture, University College, Ibadan*)

Summary

Details are given of the proximate chemical composition of twenty pasture plants cut at five varying stages of growth. The plants were grown without fertilizers on soils recovered from bush fallow in south-western Nigeria, and the characteristics of the grass species are discussed.

It was found that, in general, the crude fibre and the soluble carbohydrate content of these grasses were directly, and the crude protein, true protein, and silica-free ash were inversely related to the age and maturity at which the grass was cut. The correlation coefficients were statistically significant in most cases.

It is evident that in Nigeria, as in the temperate countries of the world, differences due to stages of growth at which the herbage is cut outweigh any differences due to species.

NIGERIA is essentially a grassland country. Over 83 per cent. of the total area consists of open savannah. Some 8 per cent. of the total land-use area is devoted to forest reserves, largely in the southern belt of the country. The further 9 per cent. of unreserved high forest land, also in the south, is often punctured by bush fallows, commonly characterized by such natural grasses as Imperata, Andropogon, Pennisetum, and Panicum. These provide bush grazing for the 'Muturu', the dwarf, trypanosomiasis-resistant, short-horned, humpless cattle indigenous to Southern Nigeria, and also for the Zebu cattle on hoof to the south from the northern part of the country.

By far the most important natural grassland of the country is the savannah, which can be divided into the Derived Guinea savannah, the Guinea savannah, the Sudan savannah, and the Sahel savannah according to the luxuriance of the growth of the grasses, the rainfall, the length of the dry season, and the humidity (Fig. 1). The savannah as a whole is characterized by a continuous sea of grasses, with scattered trees [1]. Andropogon, Hyparrhenia, Pennisetum, Chloris, Melinis, Panicum, Paspalum are the main grass genera which characterize the savannah zone.

While most of Nigeria is covered by natural grassland, no serious attempts have been made to bring these grasses into cultivation. Nigerian pastures are left in their wild natural condition without the application of the well-tested findings on the cultivation of pastures that are in use in other parts of the world. In consequence the natural grass species rapidly decline in nutritional value, becoming fibrous and coarse, since they are neither grazed nor cut for fodder at their optimum stages of growth. Their economic and nutritive values are unknown. These tough dry grasses are subject, during the dry season, to periodical burnings which result in an appreciable destruction of organic matter. It is the better grass species which are more quickly eliminated by burning since, with their delicate root system, burnt-over grasses are unable to

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VEGETATION MAP OF NIGERIA

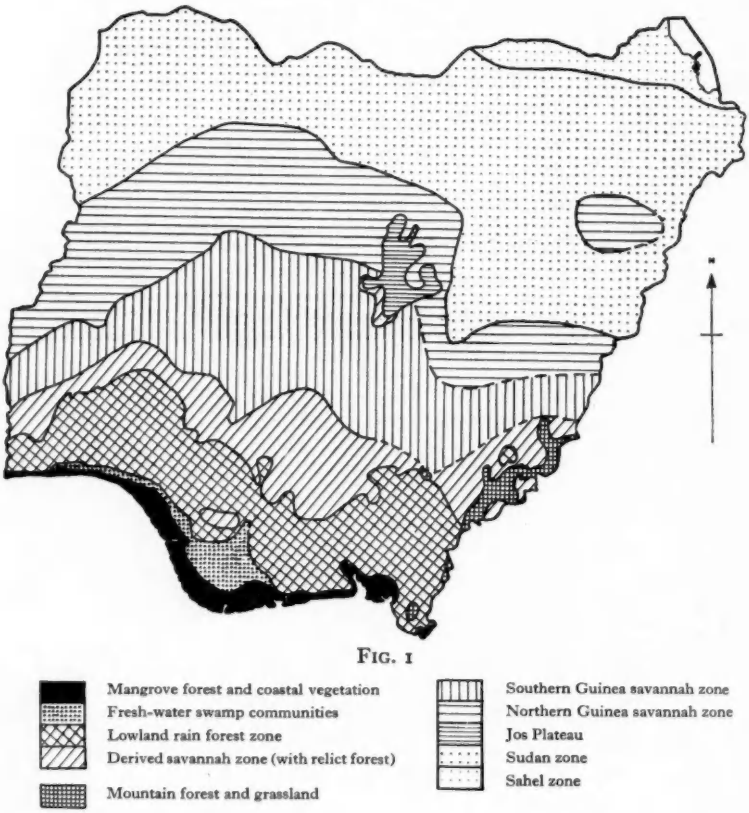

FIG. 1

withstand grazing when they are tender. Burning also destroys the surface organic matter of the soil, it damages the trees scattered all over the savannah land, it annihilates low bush, removes the shade which protects the land against the sun to conserve moisture, and thus intensifies soil erosion.

Cultivated pasture has been so late in developing in Nigeria because most of the cattle are divorced from the land. Over 90 per cent. of Nigeria's estimated 8 million head of cattle are situated in the tsetse-fly-free belt of Northern Nigeria. They are in the hands of the pastoral Fulani who do not practise settled agriculture. Although the 5 to 6 million each of sheep and goats in Northern Nigeria [2] belong to settled farmers, these animals also have not become integrated into the farm economy. Nigerian livestock, therefore, are not a part of the farming

system of the country, but are moved from place to place according to the luxuriance and availability of natural pastures and with the season. The direction of movement tends southwards as the dry season approaches and northwards during the rains.

With the desire and impetus for economic development which have accompanied the growth of political autonomy in the country, the advantages of grass cultivation are becoming more appreciated. The regional governments attach due importance to the development of animal industry. Those of the west and east have established ranching schemes consequent upon the introduction of grassland farming. Apart from the increased protein food for livestock and humans which can result from pasture development, the establishment of grassland farming would enable cultivated grass to replace natural fallow and prevent the annual loss of organic matter which accompanies the burning of natural grass. Grass-legume mixtures would check the downward movement of nutrients and bring fertility to the surface. It would prevent erosion, encourage mixed farming and settled agriculture. It would have favourable effects on the cropping practice. The rotational grazing of grass, possibly by the use of the electric fence, would facilitate the return of mineral and organic matter to the soil to replace the drain on these constituents due to the increased growth of export crops.

The Government Departments of Agriculture in their experimental stations are now introducing the well-tested methods of experimentation on grass cultivation in practice in other countries. Attempts have been made to introduce a number of exotic grass species in order to study their productivity, nutritional requirements, and nutritive values, along with the indigenous grasses, under the same environmental conditions. The Division of Animal Nutrition in the Faculty of Agriculture of the University College, Ibadan, started a series of experiments in 1952 to study the nutritive value of certain grass species indigenous to Nigeria, with a view to the eventual establishment of pasture grass. This paper reports the results of the first of these experiments.

Experimental

Material for the investigation described below was obtained from the grass plots laid down in 1952 in the Faculty of Agriculture Farm, University College, Ibadan. Twenty-five plots, each of 120 square yards (24 × 5 yards) were sown in late June 1952.

The land was ploughed from bush fallow, which had been practised before the site was acquired in 1948. Nothing else is known of the previous history of the land. *Andropogon tectorum* Schum. and *Imperata cylindrica* Beauv. dominated the bush fallow before clearing. The plots received no fertilizer treatment before or during the period of the experiment. The soil is fairly typical of that of the farm; it is just on the acid side with a pH of up to 6·8. Soil analysis[1] of the area gave the following results: total nitrogen, 0·37; P_2O_5, 0·26;[2] K_2O,[2] 0·01; CaO,[2] 0·12 per cent.

[1] Kindly carried out by Dr. F. E. S. Alexander, Lecturer in Soil Science, Faculty of Agriculture, University College, Ibadan.

[2] Soluble in 10 per cent. sodium acetate at pH 4·8 (Morgan).

Planting was carried out with cuttings of some of the tall grasses and with seeds of others. Great variations occurred in the time for establishment of the grasses, but by November 1952 they were all well established. November marks the beginning of the dry season in Nigeria and it was considered that regular cuttings would be difficult to maintain during that season. The only cutting in November was therefore discarded and the plots were allowed to grow throughout the dry season and to develop undisturbed during the following rainy season. Early in June 1953 the grasses were cut uniformly to about 6 in. and observations started from then. First samplings were made 3 or 4 weeks later and subsequent cuttings at nearly monthly intervals, except for a period of nearly 6 weeks between the second and third samplings (due to a breakdown in the electric supply which prevented the determination of dry matter in the laboratory).

Table 1 gives particulars of dates, cutting, sampling, and field observations.

For nearly all species five series of samples were taken during the course of the growing season, the first when the plants were young, leafy, and tender, the second when the leaves were more mature, the third and fourth at the flowering and seeding stages, and the last when the plants were in decline.

A strictly randomized method of cutting was not practicable at the time of sampling. Each plot was divided into five parts and samples were taken from a portion of each part. Care was taken to avoid sampling twice from the same spot during the season. Samples were cut with metal shears at a height of about 6 to 12 in. above ground according to the height of the plant, care being taken to reduce contamination to the minimum. Samples from each plot were then bulked and cut into pieces. Only the leaves were sampled in the tall grasses where the shoots had formed canes. This was thought to correspond more closely to what livestock normally eat from such grasses. Samples were then conveyed to the laboratory in paper bags and carefully picked over to exclude extraneous matter.

The first three sample cuttings were air-dried since an oven was not then available, while the last two were oven-dried at 60° C. for about 24 hours. All samples were ground in a Christie–Norris hammer-mill, using a $\frac{1}{32}$-in. sieve. The ground samples were then stored in air-tight bottles until analysed. The methods of analysis adopted have been described elsewhere [3].

Results and Discussion

Table 2 gives meteorological data at the University College, Ibadan, for the period June 1952 to December 1953, while Table 3 records the results of the analyses (pp. 242–5).

The dry-matter values are incomplete owing to a breakdown in the electric supply in August and September 1953.

It will be observed, nevertheless, that the dry matter of all the grasses increased with maturity, with increases of as much as 50 per cent. in fifth cuts compared with the first. Of the tall grasses Andropogon

Species	Date sown	Method of sowing	Date cut back	First Sampling		
				Date cut	Av. ht. (in.)	Remarks
1. *Andropogon gayanus* Kunth. (Gamba grass)	19.6.52	Seed	8.6.53	6.7.53	41	Very vigorous gro leafy preflowerin
2. *Andropogon tectorum* Schum. (Gamba grass)	27.6.52	,,	,,	,,	27	Difficult to establi Growth slow. L too broad. No young stage.
3. *Andropogon* sp. Linn. (ex South Africa)	26.6.52	,,	,,	,,	33	Young, vigorous, green shoots. Pre stage.
4. *Chloris gayana* Kunth. (Rhodes Grass) (Indigenous)	23.6.52	,,	,,	29.6.53	31	Young, fresh, leaf tion, preflowering
5. *Chloris gayana* Kunth. (Rhodes Grass) (ex Kenya)	25.6.52	,,	,,	30.6.53	20	Young, fresh, lea flowering stage.
6. *Chloris gayana* Kunth. (Rhodes Grass) (ex Sierra Leone)	,,	,,	,,	,,	15	Difficult to establis established when Young stage.
7. *Cynodon plectostachyum* Pilger (Giant Star grass)	20.6.52	Shoot	,,	10.7.53	20	Straight growth. Sc slow to establis spreading. Young leaves.
8. *Eleusine indica* Gaertn. (Gbegi grass)	9.7.52	,,	9.6.53	,,	26	Vigorous growth. leaves. Full-fl stage. Early fl species.
9. *Melinis minutiflora* Beauv. (Molasses grass)	25.6.52	Seed	20.6.52	28.7.53	24	Early growth slow, vigorous. Youn flowering stage.
10. *Panicum maximum* Jacq. (Guinea grass)	19.6.52	,,	6.6.53	26.6.53	25	Young and fresh sta vigorous growth. flowering.
11. *Panicum maximum* Jacq. (Guinea grass) (ex South America)	,,	,,	,,	29.6.53	31	Young, fresh stag very vigorous grow flowers yet appeari
12. *Paspalum conjugatum* Berg. (Green grass)	20.6.52	Shoot	8.6.53	6.7.53	26	Vigorous, young woody, scanty leav
13. *Pennisetum cenchroides* (South African Kyaswa) (ex South Africa)	25.6.52	Seed	6.6.53	26.6.53	21	Young and fresh, pre ing stage of growth
14. *Pennisetum pedicellatum* Trin. (Kyaswa grass)	23.6.52	,,	5.6.53	25.6.53	18	Young and fresh Well-established gr
15. *Pennisetum purpureum* Schum. (Purple Elephant grass)	,,	Cutting	,,	,,	37	Young and fresh cor Easily established. luxuriant.
16. *Pennisetum purpureum* Schum. (White Elephant grass)	20.10.52	,,	,,	,,	26	Young and fresh cor Preflowering stage.
17. *Pennisetum* sp. (ex Zonkwa)	18.6.52	Shoot	,,	,,	24	Young, fresh stage. established start.
18. *Setaria sphacelata* Stapf. and Hubbard (Golden Timothy grass)	20.6.52	,,	8.6.53	10.7.53	37	Vigorous, young leafy Plant hairy to the to
19. *Centrosema pubescens* Benth. (A herbaceous legume)	7.7.52	Seed	—	13.7.53	17	Vigorous, young, stage. Spreading st
20. *Tridax procumbens* (A herbaceous plant)	20.6.53	,,	No cutting back	11.9.53	28	Vigorous growth. flowering stage. shoots.

TABLE 1. *Dates of Sowing, Cutting Back, Sampling, and Stages of Growth of Grass Species*

First Sampling			*Second Sampling*			*Third Sampling*			*Fourth Sampling*			
	Av. ht. (in.)	*Remarks*	*Date*	*Av. ht. (in.)*	*Remarks*	*Date cut*	*Av. ht. (in.)*	*Remarks*	*Date cut*	*Av. ht. (in.)*	*Remarks*	
	41	Very vigorous growth, tall, leafy preflowering stage.	27.7.53	56	Growth continued vigorous. Stem getting stout. Leaves long and wide. Preflowering.	10.9.53	107	Growth still luxurious. Preflowering.	9.10.53	127	Stems getting thicker, leaves narrower, flowering beginning.	2
	27	Difficult to establish. Growth slow. Leaves not too broad. No flowers, young stage.	,,	40	Growth not as vigorous as in *A. gayanus*. Preflowering stage.	9.9.53	61	Growth improved. Preflowering, leafy stage.	,,	70	Growth luxuriant, stalk long, leaves narrow and scanty. Early flowering stage.	2
	33	Young, vigorous, fresh and green shoots. Preflowering stage.	28.7.53	47	Vigorous growth. Narrower leaves than other two species. No flowers.	10.9.53	98	Growth in length rapid, thicker stem, bushy growth. No flowers.	,,	119	Tall, leaf-blade reduced in width. Flowering stage.	2
3	31	Young, fresh, leafy condition, preflowering stage.	21.7.53	39	Vigorous growth, leafy condition; preflowering stage.	9.9.53*	66	Leafy condition.	30.9.53	76	Vigorous growth. Shoot lengthens, young, fresh and green.	2
3	20	Young, fresh, leafy, preflowering stage.	,,	23	Young, somewhat retarded growth. Preflowering stage.	9.9.53*	48	Vigorous growth. Flowering.	,,	63	Vigorous growth continued. Full- to late-flowering stage.	2
	15	Difficult to establish. Fully established when sampled. Young stage.	,,	22	Young, vigorous stage.	9.9.53*	51	Early flowering stage. Vigorous growth.	,,	58	Mature stage. Full- to late-flowering stage.	
3	20	Straight growth. Somewhat slow to establish. No spreading. Young tender leaves.	5.8.53	29	Young, vigorous growth. Branching of shoots.	11.9.53*	36	Vigorous fully established stage. Tuft at base.	9.10.53	46	Mature stage. Flowery at early stages.	2
	26	Vigorous growth. Green leaves. Full-flowering stage. Early flowering species.	,,	31	Post-flowering stage. Seeds set. Grass blades and leaves already dying back.	11.9.53	34	Leaves dried except for fresh shoots. Seeds dried and falling.	19.10.53	32	Dried stage for leaves and seeds.	3
3	24	Early growth slow, not very vigorous. Young, preflowering stage.	10.8.53	28	Improvement in growth, mat forming at base. Preflowering.	10.9.53	39	Growth luxuriant. Forming large root, with dead leaves at base. Early flowering stage.	9.10.53	41	Full-flowering stage.	2
3	25	Young and fresh stage with vigorous growth. Preflowering.	20.7.53	40	Vigorous, maturing stage. Early flowering stage.	8.9.53	88	Full- to late-flowering stage. Fully mature.	30.9.53	99	Late to post-flowering stage. Drying up at base.	2
3	31	Young, fresh stage with very vigorous growth. No flowers yet appearing.	21.7.53	46	Early flowering stage with very vigorous, mature growth.	9.9.53	91	Full- to late-flowering stage.	,,	101	Late- to post-flowering stage. Seeds fully set. Drying at base.	2
3	26	Vigorous, young growth, woody, scanty leaves.	28.7.53	34	Growth continues vigorous. Preflowering stage. Early formation of matted base.	10.9.53	50	Vigorous growth, mature stage. Early to full flowering.	9.10.53	55	Full- to late-flowering stage. Fully mature and tufty stage. Woody. Thick knot at base.	2
3	21	Young and fresh, preflowering stage of growth.	20.7.53	33	Fresh, but mature stage of growth. Early flowering stage.	9.9.53	35	Full- to late-flowering stage. Growth appeared quite normal.	30.9.53	37	Late- to post-flowering stage. Drying of lower parts.	2
3	18	Young and fresh stage. Well-established grass.	17.7.53	32	Vigorous growth, getting to mature stage. Early flowering period.	10.8.53	48	Full-flowering stage. Fully mature plant. Some drying of lower leaves.	8.9.53	70	Late-flowering stage. Drying at base more widespread.	3
	37	Young and fresh condition. Easily established. Growth luxuriant.	,,	84	Vigorous growth, young, fresh, preflowering stage, cones forming at base.	,,	118	Fully mature stage. Leaves deep purple and broad, shoots forming woody canes.	,,	147	Full mature stage with broad, coarse, tough leaf-blades. Early flowering stage.	
	26	Young and fresh condition. Preflowering stage.	,,	67	Preflowering stage. Somewhat mature stage, with broad, succulent leaves.	,,	94	Fully mature stage. Luxuriant growth. Cane formation at lower shoot. Some leaves dried at base.	,,	115	More mature plant with broad, coarse leaves. Early flowering stage.	
	24	Young, fresh stage. Well-established start.	,,	60	Fresh, preflowering stage.	8.9.53	116	Flowering stage. Luxuriant growth.	30.9.53	139	Full to late-flowering. Fully mature, somewhat coarse leaves.	2
3	37	Vigorous, young leafy stage. Plant hairy to the touch.	5.8.53	65	Vigorous, luxuriant growth. Flowering stage.	11.9.53	83	Full-flowering stage. Fully mature stage. Leaves yellowing at bottom.	9.10.53	86	Late-flowering stage.	2
3	17	Vigorous, young, leafy stage. Spreading starting.	10.8.53	32	Leaf size increased. Preflowering stage.	,,	39	Early to full-flowering stage. Mature plant.	20.10.53	40	Full- to late-flowering stage. Seeds set. Lower parts of leaf drying off.	3
3	28	Vigorous growth. Full-flowering stage. Thin shoots.	20.10.53	30	Late-flowering stage. Lower leaves already dropping.	30.11.53	32	Post-flowering and post-seeding stage. Plants have died off, and young ones starting from dropped seeds.				

* Sampling delayed (see p. 240).

Dates of Sowing, Cutting Back, Sampling, and Stages of Growth of Grass Species

Second Sampling		Third Sampling		Fourth Sampling			Fifth Sampling			Sixth Sampling		
) Remarks	Date cut	Av. ht. (in.)	Remarks	Date cut	Av. ht. (in.)	Remarks	Date cut	Av. ht. (in.)	Remarks	Date cut	Av. ht. (in.)	Remarks
Growth continued vigorous. Stem getting stout. Leaves long and wide. Preflowering.	10.9.53	107	Growth still luxurious. Preflowering.	9.10.53	127	Stems getting thicker, leaves narrower, flowering beginning.	27.11.53	189	Thick stem, narrow and scanty leaves, lower leaves drying. Widespread flowering.			
Growth not as vigorous as in *A. gayanus*. Preflowering stage.	9.9.53	61	Growth improved. Preflowering, leafy stage.	,,	70	Growth luxuriant, stalk long, leaves narrow and scanty. Early flowering stage.	20.11.53	144	Widespread flowering stage. Leaves getting narrower, stalk thicker.			
Vigorous growth. Narrower leaves than other two species. No flowers.	10.9.53	98	Growth in length rapid, thicker stem, bushy growth. No flowers.	,,	119	Tall, leaf-blade reduced in width. Flowering stage.	27.11.53	130	Leaves narrower and scanty. Thicker stalk. Widespread flowering.			
Vigorous growth, leafy condition; preflowering stage.	9.9.53*	66	Leafy condition.	30.9.53	76	Vigorous growth. Shoot lengthens, young, fresh and green.	20.11.53	96	Vigorous growth. Full flowering. Lower leaves drying off.			
Young, somewhat retarded growth. Preflowering stage.	9.9.53*	48	Vigorous growth. Flowering.	,,	63	Vigorous growth continued. Full- to late-flowering stage.	25.11.53	66	Late to post-flowering stage. Leaf drop at base widespread.			
Young, vigorous stage.	9.9.53*	51	Early flowering stage. Vigorous growth.	,,	58	Mature stage. Full- to late-flowering stage.	,,	63	Post-flowering stage. Mature, yellowing of leaves.			
Young, vigorous growth. Branching of shoots.	11.9.53*	36	Vigorous fully established stage. Tuft at base.	9.10.53	46	Mature stage. Flowery at early stages.	27.11.53	49	Post-flowering stage. Tufted at base. Very mature stage.			
Post-flowering stage. Seeds set. Grass blades and leaves already dying back.	11.9.53	34	Leaves dried except for fresh shoots. Seeds dried and falling.	19.10.53	32	Dried stage for leaves and seeds.	30.11.53	33	Post-flowering, post-seeding stage, dried leaves and seeds, brittle leaves, flowers, and seeds.			
Improvement in growth, mat forming at base. Preflowering.	10.9.53	39	Growth luxuriant. Forming large root, with dead leaves at base. Early flowering stage.	9.10.53	41	Full-flowering stage.	27.11.53	60	Fully mature stage, late and post-flowering stage. Large mat at base.			
Vigorous, maturing stage. Early flowering stage.	8.9.53	88	Full- to late-flowering stage. Fully mature.	30.9.53	99	Late to post-flowering stage. Drying up at base.	20.11.53	98	No more flowers. Seeds dropping. Drying up at base, with yellow colour on top of leaves.			
Early flowering stage with very vigorous, mature growth.	9.9.53	91	Full- to late-flowering stage.	,,	101	Late- to post-flowering stage. Seeds fully set. Drying at base.	25.11.53	103	Post-flowering and seed stage, markedly dried at base and yellow on top.			
Growth continues vigorous. Preflowering stage. Early formation of matted base.	10.9.53	50	Vigorous growth, mature stage. Early to full flowering.	9.10.53	55	Full- to late-flowering stage. Fully mature and tufty stage. Woody. Thick knot at base.	27.11.53	49	Post-flowering stage. Very tough and woody. Leaves dried at base.			
Fresh, but mature stage of growth. Early flowering stage.	9.9.53	35	Full- to late-flowering stage. Growth appeared quite normal.	30.9.53	37	Late- to post-flowering stage. Drying of lower parts.	23.11.53	35	Post-flowering, all flowers have disappeared. Leaves continued green.			
Vigorous growth, getting to mature stage. Early flowering period.	10.8.53	48	Full-flowering stage. Fully mature plant. Some drying of lower leaves.	8.9.53	70	Late-flowering stage. Drying at base more widespread.	30.9.53	78	Flowers and leaves dropping. Widespread dropping of leaves.	23.11.53	85	Grass dried with tufts at base.
Vigorous growth, young, fresh, preflowering stage, cones forming at base.	,,	118	Fully mature stage. Leaves deep purple and broad, shoots forming woody canes.	,,	147	Full mature stage with broad, coarse, tough leaf-blades. Early flowering stage.	,,	159	Full- to late-flowering stage. In full bloom. Deep purple colour.	20.11.53	185	Late- to post-flowering stage. Leaves drying at bottom, narrower and coarse leaf-blades.
Preflowering stage. Somewhat mature stage, with broad, succulent leaves.	,,	94	Fully mature stage. Luxuriant growth. Cane formation at lower shoot. Some leaves dried at base.	,,	115	More mature plant with broad, coarse leaves. Early flowering stage.	,,	132	Full- to late-flowering stage. Leaves getting somewhat coarse.	,,	147	Post-flowering stage. Withering of dry leaves, particularly lower down. Very tough, coarse leaves.
Fresh, preflowering stage.	8.9.53	116	Flowering stage. Luxuriant growth.	30.9.53	139	Full to late-flowering. Fully mature, somewhat coarse leaves.	23.11.53	140	Post-flowering stage. Lower leaves drying.			
Vigorous, luxuriant growth. Flowering stage.	11.9.53	83	Full-flowering stage. Fully mature stage. Leaves yellowing at bottom.	9.10.53	86	Late-flowering stage.	20.11.53	91	Post-flowering stage. Drying of leaves and stems, only fresh shoots remaining green.			
Leaf size increased. Preflowering stage.	,,	39	Early to full-flowering stage. Mature plant.	20.10.53	40	Full- to late-flowering stage. Seeds set. Lower parts of leaf drying off.	30.11.53	38	Post-flowering stage. Dried seeds and lower leaves.			
Late-flowering stage. Lower leaves already dropping.	30.11.53	32	Post-flowering and post-seeding stage. Plants have died off, and young ones starting from dropped seeds.									

* Sampling delayed (see p. 240).

TABLE 2. *Monthly Summary of Meteorological Data at the University College, Ibadan, June 1952–December 1953**

Month	Average monthly rainfall (in.)	Mean relative humidity (%) at 10.00 hrs.	Mean relative humidity (%) at 06.00 hrs.	Hours of bright sunshine		Mean daily temperature $\frac{max+min}{2}$ (°F.)
				Monthly totals	Daily mean	
1952						
June	5·06	94	..	167·0	..	78·0
July	7·68	93	..	87·8	..	78·0
August	1·06	94	..	87·2	..	76·0
September	5·59	92	..	94·1	..	78·0
October	6·68	91	..	136·2	..	79·0
November	4·97	93	..	202·7	..	80·0
December	1·19	94	..	176·2	..	79·0
1953						
January	0·56	88	..	190·1	..	82·7
February	4·53	76	48	168·2	6·2	82·5
March	1·43	80	52	207·6	6·7	82·0
April	1·37	78	53	195·2	6·5	83·0
May	7·12	82	65	211·5	6·8	80·3
June	7·15	84	76	143·1	4·8	78·0
July	4·52	88	78	94·1	3·0	76·5
August	1·48	88	77	41·1	1·3	74·8
September	5·30	88	72	102·1	3·4	77·6
October	5·71	85	71	165·9	5·4	78·2
November	2·15	82	61	211·4	7·0	79·7
December	0·08	70	34	244·8	7·9	78·0

* Supplied by Professor B. J. Garnier, Professor of Geography, University College, Ibadan.

appeared higher in dry matter than the Pennisetum species, which were more leafy and succulent. The shorter grasses, for example *Cynodon plectostachyum* Pilger, generally showed a higher dry-matter content than the tall grasses.

For unmanured tropical fodders, the crude-protein contents of the dry matter of all the grasses were fairly high. The mean of the five or six cuts ranged from 6·5 per cent. in *Setaria sphacelata* to 10·9 in *Pennisetum purpureum* and generally ranged from 15 to 5 per cent. from the first to the fifth cuttings, particularly in Pennisetum and Chloris. In general the Pennisetum appeared to contain more protein than any of the other grasses, followed in order by Andropogon, Paspalum, Eleusine, Chloris, Panicum, Cynodon, *Melinis minutiflora*, and *Setaria sphacelata*. The crude- and true-protein content fell rapidly with maturity, though more markedly in some species than in others. Almost throughout, the crude- and true-protein content of the grasses had a statistically significant negative correlation with the age at cutting.

Similarly, the ash content was, in general, negatively correlated with age. The Pennisetum species had the highest content of ash (except for *Setaria sphacelata*).

About 30 per cent. of the dry matter of the grasses consisted of crude

TABLE 3. *Chemical Composition of some Nigerian Grasses cut at Different Stages of Growth (dry-matter basis)*

Name of grass	*No. of cut*	*Age in weeks*	*Average height at cutting (in.)*	*Dry matter (%)*	*Crude protein (%)*	*True protein (%)*	*Ether extract (%)*	*Crude fibre (%)*	*Nitrogen-free extract (%)*	*Silica-free ash (%)*
Andropogon gayanus Kunth. (Gamba grass)	1	4	41	25·5	10·1	8·7	1·1	29·7	49·0	6·0
	2	7	56	22·8	8·5	7·7	1·1	32·1	48·3	5·5
	3	13	107	..	7·5	7·4	1·2	34·0	49·8	4·5
	4	17½	127	26·6	6·1	5·7	1·6	33·7	51·6	3·5
	5	24½	189	43·0	4·8	4·4	0·9	32·2	55·4	3·2
	Mean			29·5	7·4	6·8	1·2	32·3	50·8	4·5
	Corr. coeff.				−0·99*	−0·98*	−0·02	+0·53	+0·94†	0·98*
Andropogon tectorum Schum. (Gamba grass)	1	4	27	28·1	11·8	10·7	2·2	26·6	48·5	5·5
	2	7	40	24·9	7·9	7·9	1·2	29·1	52·0	5·5
	3	13	61	..	6·5	5·7	1·7	30·7	54·0	4·2
	4	17½	70	29·3	6·6	6·3	2·4	29·6	54·4	3·1
	5	23½	144	47·8	5·7	4·9	1·2	32·5	54·9	2·4
	Mean			32·5	7·7	7·1	1·7	29·7	52·8	4·1
	Corr. coeff.				−0·84	−0·89†	−0·21	+0·89†	+0·89†	−0·99*
Andropogon spp. Linn. (Gamba grass) (ex South Africa)	1	4	33	25·5	13·5	12·1	1·5	26·9	47·1	5·7
	2	7	47	21·4	11·6	10·5	1·1	32·2	46·5	4·6
	3	13½	98	..	9·4	9·0	1·1	31·8	50·6	4·3
	4	17½	119	36·5	7·9	6·5	1·7	34·3	49·3	4·0
	5	24½	130	57·1	5·9	5·0	0·8	34·1	52·1	2·6
	Mean			35·1	9·7	8·6	1·2	31·9	49·1	4·2
	Corr. coeff.				−0·99*	−0·99*	−0·39	+0·81	+0·91†	−0·96†
Chloris gayana Kunth. (Rhodes grass)	1	3	31	24·1	14·9	11·3	1·6	27·4	43·7	7·7
	2	6	39	29·4	8·7	8·0	1·2	32·7	46·8	6·8
	3	13	66	..	7·2	5·8	1·4	30·4	52·4	3·9
	4	16	76	..	6·3	4·9	1·5	30·3	53·1	3·9
	5	23	96	49·1	5·1	4·6	1·3	29·9	56·4	2·7
	Mean			34·2	8·4	6·9	1·4	30·1	50·5	5·0
	Corr. coeff.				−0·87	−0·91†	−0·26	+0·13	+0·98*	−0·97*
Chloris gayana Kunth. (Rhodes grass) (ex Kenya)	1	3	20	23·7	12·6	12·2	1·5	29·4	44·9	6·7
	2	6	23	26·0	9·9	9·0	1·4	29·6	47·1	6·5
	3	13	48	..	6·1	5·0	1·1	32·6	51·5	4·9
	4	16	63	..	6·5	4·6	1·2	32·0	50·9	4·9
	5	24	66	35·8	4·7	4·0	1·1	34·7	52·2	4·7
	Mean			28·5	8·0	7·0	1·3	31·7	49·1	5·3
Chloris gayana Kunth. (Rhodes grass)	1	3	15	22·4	12·8	11·6	1·5	29·9	44·0	6·6

	4	16	63	..	6·5	4·6	1·2	32·0	50·9	4·9
	5	24	66	35·8	4·7	4·0	1·1	34·7	52·2	4·9
	Mean			28·5	8·0	7·0	1·3	31·7	49·3	5·3
Chloris gayana Kunth. (Rhodes grass) (ex Sierra Leone)	1	3	15	22·4	12·8	11·6	1·5	29·9	44·0	6·6
	2	6	22	24·9	8·6	8·0	1·4	31·6	47·1	5·6
	3	13	51	..	5·9	4·5	1·3	33·7	50·4	4·5
	4	16	58	..	5·3	4·0	1·1	34·6	51·5	3·8
	5	24	63	33·0	4·1	3·6	0·8	33·4	54·1	2·4
	Mean			26·8	7·3	6·3	1·2	32·6	49·2	5·3
	Corr. coeff.				−0·91†	−0·89†	−0·98*	+0·78	+0·98*	−0·95*
Cynodon plectostachyum Pilger (Giant Star grass)	1	4½	20	33·8	11·0	9·7	1·2	29·5	47·6	6·4
	2	8	29	31·6	8·9	8·0	1·1	31·0	49·5	5·8
	3	13½	36	..	6·2	4·6	1·0	31·9	51·9	5·2
	4	17½	46	37·1	6·3	5·2	1·2	30·1	54·2	3·9
	5	24½	49	42·9	5·2	4·3	0·8	30·3	56·1	4·5
	Mean			36·4	7·5	6·4	1·1	30·6	51·9	5·2
	Corr. coeff.				−0·93†	−0·89†	−0·68	+0·08	+0·99*	−0·86
Eleusine indica Gaertn. (Gbegi grass—Yoruba)	1	4½	26	36·5	11·5	9·0	1·3	29·3	48·2	4·9
	2	8	31	39·7	8·3	7·8	1·0	32·2	49·7	4·2
	3	13½	34	..	7·1	6·2	1·2	34·5	48·6	3·0
	4	19	32	50·8	7·5	6·4	1·2	33·8	48·4	2·4
	5	25	33	57·5	6·9	6·4	0·4	30·1	53·7	3·1
	Mean				8·3	7·1	1·0	32·0	49·7	3·5
	Corr. coeff.				−0·79	−0·83	−0·71	+0·15	+0·69	−0·82
Melinis minutiflora Beauv. (Molasses grass)	1	4½	24	20·6	9·8	9·1	1·2	32·1	48·1	5·3
	2	6½	28	21·3	7·9	7·2	0·9	32·3	50·1	7·5
	3	11	39	..	6·9	5·9	1·5	33·8	50·2	4·0
	4	15	41	30·0	4·9	4·4	2·4	34·3	51·3	3·9
	5	21	60	45·8	4·7	4·1	1·8	36·2	51·0	3·6
	Mean			29·4	6·8	6·1	1·6	33·7	50·1	4·9
	Corr. coeff.				−0·94†	−0·93†	+0·67	+0·99*	+0·81	−0·73
Panicum maximum Jacq. (Guinea grass) (Yoruba = Ikin)	1	3	25	17·2	13·5	10·2	1·1	28·3	37·5	11·5
	2	6	40	22·9	8·7	7·0	1·0	32·8	42·9	8·3
	3	13½	88	..	8·4	7·4	1·4	36·8	42·0	5·0
	4	17	99	..	5·9	4·7	0·9	34·4	47·7	4·8
	5	24	98	52·7	4·4	3·9	0·7	36·7	46·6	4·6
	Mean			30·9	8·2	6·6	1·0	33·8	43·3	6·8
	Corr. Coeff.				−0·92†	−0·90†	−0·51	+0·83	+0·83	−0·89†

* Significant at P = 0·05.

† Significant at P = 0·01.

TABLE 3 (*contd.*)

Name of grass	*No. of cut*	*Age in weeks*	*Average height at cutting (in.)*	*Dry matter (%)*	*Crude protein (%)*	*True protein (%)*	*Ether extract (%)*	*Crude fibre (%)*	*Nitrogen-free extract (%)*	*Silica-free ash (%)*
Panicum maximum Jacq. (Guinea grass) (ex. South America)	1	3	31	20·7	12·1	10·0	1·0	26·2	44·9	9·3
	2	6	46	24·2	7·9	7·3	0·6	32·5	46·5	6·8
	3	13½	91	..	5·9	4·3	0·8	37·2	46·5	5·8
	4	17	101	..	5·0	4·7	0·7	36·5	47·5	5·2
	5	25	103	36·6	3·9	3·4	0·8	36·4	48·8	3·6
	Mean				7·0	5·9	0·8	33·8	46·8	6·1
	Corr. coeff.				−0·91†	−0·91†	−0·19	+0·79	+0·94†	−0·95†
Paspalum conjugatum Berg. (Green grass) Ladikoro (Yoruba vernacular)	1	4	26	23·0	10·7	8·9	1·2	29·5	45·9	8·5
	2	7	34	23·1	6·6	5·9	1·2	31·1	51·8	4·9
	3	13½	50	..	5·7	5·2	1·0	33·5	54·1	5·2
	4	17½	55	28·2	5·3	4·4	1·8	28·6	60·0	2·2
	5	24½	59	26·6	4·6	3·8	1·0	29·2	59·0	5·3
	Mean				6·6	5·6	1·2	30·2	54·2	5·2
	Corr. coeff.				−0·84	−0·89†	+0·02	−0·25	+0·91†	−0·55
Pennisetum cenchroides South African Kyaswa (ex South Africa)	1	3	21	16·1	11·6	9·3	0·6	30·2	38·7	11·5
	2	6	33	23·8	8·1	6·6	1·3	35·9	29·2	10·6
	3	13½	35	..	6·6	5·7	1·1	32·2	44·5	6·1
	4	17	37	..	5·1	3·8	1·1	30·8	47·8	5·5
	5	24½	35	38·0	4·9	4·2	1·1	32·5	47·5	4·6
	Mean				7·3	5·9	1·0	32·3	43·5	7·7
	Corr. coeff.				−0·90†	−0·88†	+0·38	−0·10	+0·94†	−0·95†
Pennisetum pedicellatum Trin. (Kyaswa grass) (ex Zaria)	1	3	18	17·1	11·9	9·8	1·1	29·2	39·7	10·6
	2	6	32	15·9	9·2	7·6	1·1	31·6	44·2	8·4
	3	9	48	16·1	7·1	6·6	1·2	34·5	46·3	6·0
	4	13½	70	..	6·3	5·9	1·3	38·7	44·8	5·1
	5	17	78	..	6·3	5·3	1·2	37·6	47·1	3·9
	6	24½	85	70·1	4·7	4·7	1·0	39·0	47·1	3·3
	Mean				7·6	6·7	1·2	35·1	44·9	6·2
	Corr. coeff.				−0·90†	−0·91†	−0·19	+0·90†	+0·77	−0·92†
Pennisetum purpureum Schum. (Purple Elephant grass) (Esun pupa—Yoruba)	1	3	37	15·3	14·0	11·9	1·2	27·4	34·9	8·3
	2	6	84	17·7	12·2	9·9	1·6	30·7	40·1	8·6
	3	9	118	15·9	10·2	9·3	1·5	31·2	42·7	6·7
	4	13½	147	..	10·8	9·1	1·7	28·9	45·6	5·6
	5	17	159	..	10·2	8·1	1·7	28·6	45·7	4·2
	6	24	185	36·7	8·0	7·0	1·7	28·2	48·0	3·8
	Mean				10·9	9·2	1·6	29·2	42·8	6·4
				18·0	12·8	11·6	1·1	27·3	35·0	13·8

	6	24	185	36·7	8·0	7·0	1·7	28·2	48·0	3·8
	Mean				10·9	9·2	1·6	29·2	42·8	6·2
Pennisetum purpureum Schum. (ex Maigana) (Elephant grass) (Efun funfun—Yoruba)	1	3	26	18·0	12·8	11·6	1·1	27·3	35·0	13·8
	2	6	67	19·3	10·4	8·8	1·2	32·1	39·2	9·9
	3	9	94	15·2	8·4	7·9	1·3	33·5	42·2	7·5
	4	13½	115	..	8·1	6·7	1·4	31·1	44·7	6·2
	5	17	132	..	8·5	6·4	1·4	30·6	44·5	5·4
	6	24	147	51·0	6·9	5·9	1·5	30·7	46·7	3·5
	Mean				9·2	7·9	1·3	30·9	42·1	7·7
	Corr. coeff.				−0·86†	−0·89†	+0·96*	+0·17	+0·92†	−0·93†
Pennisetum spp. (ex Zonkwa)	1	3	24	17·8	12·6	11·3	1·0	26·0	35·0	15·5
	2	6	60	20·0	10·8	8·6	1·1	30·9	42·3	8·8
	3	13½	116	..	8·9	7·6	2·2	29·8	46·4	5·4
	4	17	139	..	7·6	5·7	1·7	28·9	49·5	4·2
	5	24½	140	39·1	5·5	4·6	2·1	30·6	49·2	2·9
	Mean				9·1	7·6	1·6	29·2	44·5	7·4
	Corr. coeff.				−0·99*	−0·96†	+0·84	+0·52	+0·89†	−0·90†
Setaria sphacelata Stapf and Hubbard (Golden Timothy grass)	1	4½	37	14·8	10·9	9·0	1·7	30·8	40·4	12·3
	2	8	65	22·0	7·3	6·7	1·2	30·1	47·7	10·5
	3	13½	83	..	4·9	4·3	1·4	32·1	49·3	8·2
	4	17½	86	25·4	4·7	4·0	1·7	35·0	47·8	6·2
	5	23½	91	27·8	4·6	3·9	1·2	36·8	45·2	5·8
	Mean				6·5	5·6	1·4	33·0	46·1	8·1
	Corr. coeff.				−0·86	−0·89†	−0·32	+0·95†	+0·38	−0·97*
Centrosema pubescens Benth. (A herbaceous legume)	1	0	17	30·3	16·6	16·1	1·4	31·3	43·2	6·0
	2	4	32	24·4	15·8	14·2	1·2	30·3	45·5	5·8
	3	8½	39	..	17·2	15·6	1·5	30·6	43·3	5·7
	4	19	40	32·6	18·7	15·3	2·2	29·8	40·9	7·2
	5	25	38	30·6	16·0	14·7	1·8	31·3	43·0	6·2
	Mean				16·9	15·2	1·6	30·7	43·2	6·2
	Corr. coeff.				+0·25	−0·32	+0·79	−0·08	−0·55	+0·57
Tridax procumbens (A herbaceous plant)	1	12	28	..	10·5	9·5	0·8	22·0	26·9	9·6
	2	17½	30	13·0	9·2	9·0	1·4	28·2	47·5	11·4
	3	23	32	17·2	10·2	9·2	1·5	33·2	40·5	10·7
	Mean				10·0	9·2	1·2	27·8	38·3	10·6

* Significant at P = 0·05. † Significant at P = 0·01.

fibre the content of which shows a positive correlation with the age at which the grass was cut. The results for the individual grasses are discussed below.

Andropogon spp. There are many varieties of Andropogon indigenous to tropical Africa. Edwards and Bogdan [4], for instance, mention *Andropogon chrysostachyus* Steud as one of the more important grasses of Kenya, with *A. pratensis* Hochst and *A. chinzii* Hach less so. *A. gayanus* Kunth and *A. tectorum* Schum are common grasses indigenous to Northern and Southern Nigeria respectively, where they form important species in bush fallows.

A. tectorum is a tufted grass with cane-like flowering shoots up to 15 ft. high, with leaf-blades $\frac{1}{2}$ to $\frac{3}{4}$ in. in diameter. The leaf-blade narrows rapidly with maturity, losing its fleshy succulent smoothness and tapering into narrow needle-like leaves with robust stems. When young, the leaves are highly palatable to livestock. It is not a spreading grass, although when grown closely enough it holds the soil sufficiently well to prevent erosion.

It will be observed from Table 3 that each of the three species of Andropogon investigated was a fairly good source of protein, the exotic South African species being somewhat better than *A. tectorum* Schum which, in turn, was slightly richer in this nutrient than *A. gayanus* Kunth. There were no appreciable differences in their ash content.

A. gayanus, on the other hand, tended to be more fibrous with somewhat less soluble carbohydrate than the other two varieties. The dry-matter content fell uniformly in the three varieties at the second cutting, when the grasses had grown for about 7 weeks after first cutting back.

At Moor Plantation, Ibadan, an average yield of 4·4 tons per acre of edible fodder was obtained for the 3-year period 1945–7 from *A tectorum*. In another experiment by the author, in which *A. tectorum* was given a much closer study, the mean yield of green fodder in tons per acre rose from 6·5 when cut at 3-weekly to 12·1 at 6-weekly intervals. However, when cut at longer intervals, 8- and 12-weekly, the yield of fresh fodder fell to 10·4 and 7·1 tons per acre respectively.

Of the three species of Andropogon, *A. gayanus* was poorest in protein and nitrogen-free extract, somewhat high in ash, and higher than *A. tectorum* in crude fibre. It was much inferior to the other two species in its yields of edible fodder. Both *A. gayanus* and the exotic South African species rapidly declined with maturity in respect of crude and true protein and ash. (The negative correlation coefficients for these nutrients in *A. gayanus* were significant at $P = 0{\cdot}01$, but only at $P = 0{\cdot}05$ with *A. tectorum*.)

Chloris gayana Kunth. (Rhodes grass). Rhodes grass was described by Edwards [5] and by Edwards and Bogdan [4] as a useful pasture plant widely distributed in Kenya. A full botanical description of the grass is given by Hubbard [6].

This grass is a perennial which spreads rapidly by rooting runners. It occurs naturally in various parts of southern and the middle belts of Nigeria. The indigenous type described in this investigation was originally taken from Ilorin. It attained a height of from 2 to 8 ft.

with somewhat broad leaves, the luxuriance and greenness of which varied with the fertility and the moisture content of the soil.

Rhodes grass forms a good pasture for grazing stock. Owing to its erect stems, it can be cut for fodder and provided it is well cured can furnish very good hay. It is a heavy yielder and several cuttings a year could be made of the well-established grass.

It will be observed from Table 1 that the indigenous strain (ex Ilorin) grew taller than the exotic types (ex Kenya and ex Sierra Leone), the former reaching 96 in. and the latter 66 and 63 in. respectively at the fifth cutting. These differences in height were due more to the height of the elongated inflorescence which, at the mature stage, became very prominent in the indigenous type, probably at the expense of the leaves, which got rapidly fewer as maturity progressed.

The indigenous type was also richer in crude protein, oil, and soluble carbohydrates than the two exotic strains, the latter containing higher amounts of crude fibre and ash. The preliminary sampling which took place in November 1952, however, showed that the strains from Kenya and Sierra Leone produced higher nutrients per acre than the indigenous strain. The following yields of fresh edible fodder were obtained:

Ex Kenya	47	cwt. per acre
Ex Sierra Leone	46·5	„ „
Ex Ilorin (indigenous) . . .	25	„ „

Based on these yields the strain from Kenya yielded 3·8, that from Sierra Leone 3·4, and ex Ilorin 2·1 cwt. crude protein per acre.

All the strains declined rapidly in quality with maturity, with a fall in protein, ash, and ether extract and a rise in crude fibre and nitrogen-free extractives, most of the negative or positive correlations being fairly significant.

Cynodon plectostachyum Pilger (Giant Star grass). The Giant Star was one of the grasses mentioned in 1944 as receiving attention for purposes of establishing pasture grass in Southern Nigeria [7]. Hitherto no further information about this grass seems to be on record in Nigeria.

Cynodon plectostachyum Pilger is a spreading perennial with long and rapidly growing stolons. It may grow up to 4 ft. high when fully established and uncut. Although it has been described as producing abundance of seeds [5], the author's field observations have not confirmed this. Once established, Giant Star grass covers well, grows luxuriantly and persistently, and withstands grazing well. Mixed with *Centrosema pubescens*, it has been used continuously for over 6 years as a grazing sward for cattle, sheep, and poultry in the Faculty of Agriculture Farm, University College, Ibadan.

Table 3 shows this grass to be a fairly good source of proteins and ash, both of which fell as the grass increased with age, and of nitrogen-free extract, which is positively correlated with age. Giant Star is a highly promising grass for sward establishment in Southern Nigeria. In East Africa it has been cut for hay and silage [8], the digestibility of which have been shown to be fairly high.

Eleusine indica Gaertn. (Crow-foot grass) is an erect or spreading long-

season, annual grass, which is commonly found in waste places as well as in cultivated grounds in both the moist and dry parts of Nigeria. It possesses a deeply penetrating fibrous root system which forms a mat. For this reason it usually proves difficult to eradicate, particularly from cultivated arable land. It has been described, for the same reason, as useful for binding river banks, dams, and loose earth and thus for checking erosion.

This grass was established vegetatively, although it could also be propagated from seed. It became established extremely rapidly and produced flowers and seeds within 4 to 7 weeks of planting. Its heavy yield of fresh grass and hay, although somewhat hard to the touch, was nevertheless palatable to most livestock.

It is rich in protein, but very poor in ash. Its fibre content rose to a maximum and then declined when the grass was left uncut for about 5 months. The rate of decline of its protein, ether extract, and silica-free ash, and of rise of its crude fibre and nitrogen-free extract, with increasing maturity, was less marked than in the other tropical grasses reported (none of the correlation coefficient figures for these nutrients was significant).

Melinis minutiflora Beauv. (Molasses grass) is an indigenous perennial commonly found in most tropical countries. It grows to a height of 5 ft. and tends to form spreading tufts. The viscous, densely hairy leaf is about 2 to 7 in. long and $\frac{1}{6}$–$\frac{1}{2}$ in. wide, with a characteristic smell. A full botanical description is given by Hubbard [6].

Melinis is a valuable grazing and fodder grass which forms a close sward, producing heavy yields of edible fodder. The sample of this grass cut in November 1952 gave a yield of over 90 cwt. of edible fodder per acre. Once they are accustomed to it, the grass is well relished by livestock.

Molasses grass establishes well by seed which it produces in abundance. It can also be grown vegetatively. It easily covers the soil and smothers weeds. It can also be easily eradicated on cultivated land. Owing to its viscous nature, it is repellent to ticks and other animal parasites, for which reason it has been suggested as a possible repellant to tsetse fly [6].

The crude- and true-protein content of this grass as well as the nitrogen-free extract were fairly high. It was, however, low in ash and ether extract. Like other grasses studied, the crude fibre rose and the proteins and ash fell with increasing maturity (the correlation coefficients were all highly significant).

Panicum maximum Jacq. (Guinea grass) grows naturally in many parts of Nigeria. It is used in some of the rural areas as a roofing material and as such it is sometimes sold in the market. It has been introduced from Africa, its original home, into various tropical and sub-tropical countries in South and Central America, the sub-tropical parts of North America, the Caribbean islands, India, Ceylon, Malaya, Indonesia, and Queensland. It is reported to have played an important part in grassland improvement and livestock production in some of these countries [9]. The results for this grass in Table 3 were obtained from samples of an exotic

South American strain, and an indigenous strain grown under identical conditions.

As a valuable animal food both as fodder and as a component of grass-legume grazing pasture Guinea grass has been fairly widely studied in various parts of the tropics. Hubbard [10] and Edwards and Bogdan [4] have given the botanical description and the distribution of this grass in East Africa. According to the last-named authors, Guinea grass is found from sea-level to an altitude of 6,500 ft. Studies of its nutritional requirements have been made in Jamaica [11, 12, 13], while the influence of the time of cutting on its yield and composition have been reported in El Salvador [14], in Jamaica [12, 15], and in Queensland [16]. Warmke [17] in Puerto Rico, White [18] in Queensland, and Mundy [19] in Southern Rhodesia studied the strains of the grass cultivated in their own respective areas. Yields of up to 48 tons of green fodder per acre per annum had been reported by Jacobson [20] from the Philippines and by Schofield from Australia [16]. In the latter case the annual yield of green fodder varied from 15 tons for monthly to 36 tons for 3-monthly cuts. Yield results reported from Malaya [21, 22, 23], however, were much lower, varying between 13 and 16 tons of green fodder per acre per annum.

Figures published by Ellis [11] and by Ellis and Burrows [12] on the crude-protein content of Guinea grass grown with and without fertilizers in Jamaica showed a range from 8 per cent. for cuts at 4- and 6-weekly intervals to 4 per cent. for cuts at approximately 3-monthly intervals. The response of this grass to a complete NPK dressing was insignificant under these conditions. Results by Watkins and Severen [14] for Guinea grass grown in El Salvador were of the same order, ranging from a maximum of 9 per cent. in January for monthly cuts to 5 per cent. for 3-monthly cuts in August. The range of 11·3 and 4·6 per cent. recorded by Schofield [24] respectively for monthly and 3-monthly cuts in Queensland is higher than the above.

The results in Table 3 for Guinea grass are in general agreement with those of Schofield [24], when account is taken of the time of cutting. The dry matter contained 13·5 per cent. crude protein when the indigenous strain was cut at 3 weeks and 4·4 per cent. when approximately 6 months old. For the exotic South American strain the corresponding figures were 12·1 and 3·9 per cent., giving a general average of 8·2 and 7·0 per cent. for these two strains. The ash content of this grass is one of the highest recorded for the tropical grasses studied. Both nutrients followed the normal trend; the amount of each diminished with smaller frequency of cutting (the negative correlation being significant in each case).

The high nutritive value, palatability to stock (particularly cattle), heavy yield, perennial and drought-resisting nature, and the ease of establishment by roots, if not by seed, make Guinea grass one of the most promising fodder grasses in the tropics. As already mentioned it is a heavy yielder. Results of yields obtained by the author with the indigenous strain grown without fertilizers in Southern Nigeria varied from 20 to 28 tons of green fodder (4·8–9·3 tons dry matter) per acre for 3-weekly to 12-weekly cuts. The yield per acre of crude protein varied from 14 to 26 cwt.

It will be noted from Table 3 that the indigenous strain appeared richer than the exotic South American strain in crude and true proteins, ether extract, and ash. The latter strain, however, produced a somewhat heavier yield of green fodder.

Paspalum conjugatum Berg. (Green grass). Paspalum is a creeping grass which is found naturally under the moist conditions of Southern Nigeria. It was established vegetatively by shoot cuttings obtained from the surrounding bush. It has a ribbed, somewhat flattened stem with short leaves about ½ in. wide at the base. It sometimes attains a height of about 4 ft., although it is not a tall grass by tropical standards. It is perennial and withstands drought, its spreading habit enables it to cover rapidly and well and conserve underlying moisture.

This grass is fairly rich in crude protein and ash, which amounted to 10·7 and 8·5 per cent. respectively in the dry matter when sampled at 4 weeks after cutting back. The protein and ash, however, diminished rapidly, since 7 weeks after cutting back these constituents had fallen respectively to 6·6 and 4·9 per cent. The crude fibre and the soluble carbohydrates rose accordingly. The analyses recorded in Table 3 are similar to those for samples from Java and British Honduras analysed at the Imperial Institute [25] except that the stages at which those samples were cut were not indicated.

Paspalum is palatable to stock, although it tends to mat rapidly at the bottom, due to its rapid rate of maturity.

Pennisetum spp.

P. pedicellatum ('Kyaswa' grass) is an early-maturing annual with a red flower-spike. It can attain a height of over 5 ft. when left uncut, but under good management it is a low grass admirably suited for grazing, particularly when grown mixed with a leguminous plant. The grass is widely distributed, particularly in the Northern Province, where it is commonly found near villages and ant-hills. It also grows fairly well in the south.

'Kyaswa' is easily established from seed. It provides a good cover at a seed rate of 6–8 lb. per acre. Once established and well managed, it tends to regenerate from year to year. It has been successfully used for grazing in many of the Government Experimental stations, particularly in Northern Nigeria, where it probably ranks second to none as a valuable grazing grass. At Gusau Agricultural Station, Kyaswa grass has been successfully used for grazing and as silage. First-, second-, and third-year Kyaswa plots were well established as ley, the second- and third-year ones being due to self-regeneration from the seeds from the first year. According to Rains (unpublished work), yields up to 3½ tons of dry matter were obtained in Northern Nigeria when this grass was cut 12 weeks after sowing. The yield of crude protein (5 per cent. of dry matter) was 441 lb. per acre.

It will be observed from Table 3 that the 'Kyaswa' grass sample contained high amounts of protein and ash, which, as in other grasses, fell with increasing maturity, while the fibre and soluble carbohydrate rose.

P. cenchroides (South African 'Kyaswa') is an exotic, South African

strain of *P. pedicellatum* and both grasses are similar in composition, except that *P. cenchroides* is not as fibrous as the local 'Kyaswa'.

P. purpureum Schum. (Elephant grass: Napier grass). The aggressive manner of growth, heavy yield, high nutritive value, palatability to livestock, drought-resisting ability, and persistent growth over a number of years are features which make Elephant grass one of the best investigated, and about the foremost of the tropical fodder grasses. Reports have appeared of its study in East Africa [4, 5, 6, 26], El Salvador [14, 27], Jamaica [11, 12, 13], Trinidad [28, 29, 30], Puerto Rico [31], and India [15]. Its botanical description, distribution, and ecological aspects have been described [5, 6, 26, 29].

P. purpureum is an indigenous grass distributed all over Nigeria. It is one of the constituents of bush fallow in the south and middle belt areas. Its leaves tend to be broader and its yield heavier in the wetter south than in the drier north. It is a deep-rooted and drought-resistant grass. It holds the soil together efficiently, for which reason it has been used extensively against erosion in contour lines in East and South Africa [32, 33, 34].

Three strains of the grass were included in the present study: the purple-pigmented variety, which was probably introduced into the country some years ago; the ordinary white variety found in the south; and the strain which is normally indigenous to Northern Nigeria (ex Zonkwa). It will be noted that these attained heights from 12 to over 15 ft. when 6 months old, the exotic, purple-coloured variety being the most prolific.

This grass is much more succulent than most of the others reported in this paper. The dry-matter content rose from 15 per cent. at 3 weeks to about 37 per cent. over 6 months after cutting back. The crude-protein content of the purple variety was greater than in the other strains; it fell from 14 per cent. of the dry matter when cut at 3 weeks to 8 per cent. when cut at approximately 6 months. The other two varieties, however, appeared richer in mineral matter than the purple variety. It is noteworthy that although the latter attained on the average greater heights than the other two at similar stages of cutting, its crude-protein content was greater than that of the others, which were less tall, a fact indicating that crude-protein and ash content are related more to maturity than to height at cutting.

Unlike most of the other tropical grasses studied, the ether-extract content of elephant grass increased steadily with age, the positive correlation coefficient being highly significant in one case. Since only the leaves (the portion which is normally eaten by stock) were sampled for analysis, the crude-fibre content did not show much rise with age, but tended to fall after reaching a maximum.

Much work had been done on the yield of Elephant grass. Paterson [29] was the first to show that under Trinidad conditions yield was heaviest when the grass was cut every 3 months. More frequent cuttings (e.g. as often as 4 weeks) had an adverse effect on the persistence of the grass. Four-monthly cutting cycles were recommended by Innes [13] in Jamaica in order to obtain the maximum yield of dry matter. Watkins

and Severen [14] suggested cutting every 3 months at a height of 8 in. for conditions prevailing in El Salvador. Yield in the above cases varied between 24·1 tons for the 4-weekly to 42·7 tons for the 12-weekly and 52 tons per acre for the 4-monthly cuts. In a detailed investigation the author obtained heavier yields of green matter per acre than those mentioned above, without the use of fertilizers, in south-western Nigeria, varying from 29 tons for 3-weekly to 53 tons per acre for 12-weekly cuts. Yields of crude protein were substantially higher than those reported by Paterson (Table 4).

TABLE 4. *Yields of Crude Protein of Elephant Grass in Trinidad and in Nigeria* (*tons per acre*)

Trinidad [28]		*Nigeria*	
Cut	*Yield*	*Cut*	*Yield*
4-weekly	0·34	3-weekly	0·70
8- ,,	0·42	6- ,,	0·80
12- ,,	0·52	8- ,,	0·92
		12- ,,	1·32

Elephant grass is a highly palatable food to cattle and horses. It is also highly digestible [28, 30]. Grazing the young grass with cattle at the Government Agricultural Station, Moor Plantation, Ibadan, led to an increased milk yield. When stock were moved from the Pennisetum field to one of *Cenchrus ciliaris* there was a noticeable drop in milk yield. Similar observations were reported at Njojo in Kenya [35] where cows put on a Pennisetum field gave a 12 per cent. increase in milk yield.

The result obtained from the present analyses showed that, of the tropical grasses examined, *Pennisetum purpureum* is one of the most valuable sources of nutrients. When grazed or cut at a height of about 3 to 4 ft., when 3 weeks old, its content of protein and ash are high and its fibre low. It is, however, best cut for fodder when about 12 to 13 weeks old, a stage when quality seemed best related to quantity.

Setaria sphacelata Stapf and Hubbard (Golden Timothy grass), also known as Rhodesian Timothy, is a tufted perennial which varied from 3 to 8 ft. high. Its leaf is between $\frac{1}{8}$–$\frac{1}{2}$ in. wide and sometimes over 1 ft. long. It was established from shoot-cuttings, although according to Edwards and Bogdan [4] it could be grown from seed. The grass is fairly well distributed all over Nigeria.

This grass is drought-resisting and perennial. It recovers fairly quickly after grazing or cutting back. It is palatable to livestock and is a good fodder grass, particularly when cut at the young stage. However, it flowers very quickly and this is accompanied by rapid maturity and coarseness, a stage at which both its palatability and yield become greatly reduced owing to a high stem–leaf ratio.

It will be observed in Table 3 that *Setaria sphacelata* was richer in ash than any of the other grasses examined: its content varied between 12·3 and 5·8 per cent. of the dry matter with a mean of 8·6 per cent. Its crude- and true-protein as well as its crude-fibre content were also high.

The last-named constituent rose almost as definitely and rapidly as the former declined with maturity and age of the grass.

Centrosema pubescens Benth is a well-known herbaceous leguminous plant widely used in admixture with grass in most parts of tropical Africa including Nigeria. It is often grown in conjunction with such grasses as *Chloris gayana*, *Melinis minutiflora*, *Panicum maximum*, and *Cynodon plectostachyum*. It then smothers weeds by its excellent covering properties, conserves moisture, enriches the nitrogen content of the soil and of the sward, and imparts increased palatability to the mixture produced. It is easily established from seed which it produces in abundance, particularly when supported and encouraged to climb.

This plant was sown in July 1952 and, like the grasses, was left uncut that year. It persisted during the intervening dry season and was allowed to re-establish itself properly during the rainy season of 1953, when sampling commenced. It was therefore not cut at the very young stage of development. The sample analysed consisted of the leaves and vines.

It will be observed in Table 3 that the dry-matter content varied between 24 and 33 per cent. when fully mature, the crude protein between 16 and 19 per cent. and the silica-free ash between 6 and 7 per cent. of the dry matter. This result would appear to show that once mature, this leguminous herb varies but little in its proximate chemical constituents (proteins, ash, crude fibre, and soluble carbohydrates).

Tridax procumbens. Interest in this common composite weed was first aroused in 1942 when it was noticed at Minna, Northern Nigeria, that pigs were extremely fond of it. It was later observed at the Government Experimental Station, Moor Plantation, Ibadan, that poultry also had a liking for it. Samples of its leaves were accordingly analysed by the Agricultural Chemist, Ibadan.

Tridax is a low-lying creeper, often found on lawns in various parts of Nigeria during the rainy season. It is most readily established from seed and once it germinates it grows extremely rapidly, producing flowers and seeds within 2 months. It is thus a short-lived annual, but it readily regenerates by means of its seeds, which it produces profusely. It attains a maximum height of about 2 ft. 8 in. when fully grown.

The sample cut and reported here was sown in mid-June 1953. By September it was already in full flower. It was possible to take samples only at three stages before the plant died off.

The sample analysed consisted of the stems, the elongated inflorescence, and the leaves. This was considered appropriate, as being the portions that livestock normally graze. As seen from the dry-matter figures (between 13 and 17 per cent.) the plant is extremely juicy. The protein content did not appear higher than that of some of the grass samples at a stage where the crude fibre varied between 22 and 33 per cent. of the dry matter. The average ash content was about 11 per cent. Its ether extract rose gradually with age.

The protein and ash of this plant were low, due probably to the fact that it was cut at a mature stage and also because the sample analysed included the stems, flowers, and seeds. Analyses of the oven-dried leaves

by Vine (private communication) gave a much higher protein and mineral content (Table 5).

TABLE 5. *Analysis of* Tridax procumbens *Leaves (dry-matter basis)*

	%		%
Crude protein . . .	26·3	K_2O	8·4
Crude fibre	17·0	CaO	4·6
Ether extract . . .	1·8	P_2O_5	1·1
Soluble carbohydrate . .	39·0	MgO	1·7
Soluble ash	15·9	..	..

The tropical grass species already discussed are low in crude protein and high in crude fibre when compared with temperate grasses cut at similar stages of growth. The dry-matter content of *Chloris gayana*, for example, cut 4 weeks after first cutting back, contained only 14·9 per cent. crude protein, and that of *Melinis minutiflora* at approximately the same age was 9·8 per cent. Of the grass species investigated, these two contained the highest and lowest amounts of protein respectively, and are considerably lower than those which have been frequently recorded in the United Kingdom for good grasses such as Italian Rye grass, Timothy, or Cocksfoot, cut at a similar stage of growth. This lower quality of herbage is to be expected since work so far carried out on the improvement of these grass species—breeding and selection, nutritional and ecological requirements—is negligible and since the fertility of the soil in which the grasses were grown was not high. Moreover, the intensity of management of Nigerian soil is low when compared with practice in the more developed parts of the world. The figures in Table 3, therefore, indicate the constituents of natural grass species grown on land which had been left to regain fertility under bush fallow in conditions prevailing in south-west Nigeria.

It seems obvious that the differences in composition which occur among the various grass species examined are not nearly as great as those recorded for the same grass cut at different stages of growth. *Andropogon gayanus* cut every 6 months, for example, contained only 4·8 per cent., or less than half as much protein as when cut every 4 weeks (10·1 per cent.). The variation is even more pronounced in Guinea grass, in which the crude protein contents in 4-weekly cuts (12·1 per cent.) fell to less than one-third (3·9 per cent.) when cut at approximately 6 months old. Differences due to the stage of growth at which the grass is cut, therefore, evidently outweigh any differences due to species. This is probably due to the relative leafiness and lushness of the young grass, a fact already well established for grasses grown in temperate countries.

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CLOVER ESTABLISHMENT ON POWER-STATION WASTE ASH

W. J. REES AND JANE WARWICK

(*Botany Department, The University, Birmingham*)

WITH PLATE 3

Summary

Two varieties of white clover have been grown on the summit of an ash-tip with and without a 2-inch surface layer of soil, together with an initial dressing of fertilizer. Growth of variety S.100 far exceeded that of variety S.184 on ash alone, or with soil.

There was no significant difference between the yields on ash alone and with soil, for either variety. High yields of fresh material were obtained from variety S.100.

Comparisons have been made between the S.100 plants grown on ash and those grown on a local farm. These include flower-head and seed production, seed viability, and leaf nutrient status. No great difference was found.

Both of the varieties of clover plant are immune to damage from high levels of aluminium or manganese, which produce toxicity symptoms in some other crop plants.

INVESTIGATIONS by Rees and Sidrak [1] into the plant-ash nutritional relationship of pulverized fuel waste or 'fly ash' indicated that this substance contained an adequate amount of all plant nutrients except nitrogen. The proportions between the various elements present may, however, vary somewhat from those found in normal soils. There were also indications that some metals may be present at toxic or near-toxic levels, manganese and aluminium in particular. Crops seeded on ash require repeated additions of nitrogenous fertilizers. This shortage of nitrogen has also been reported elsewhere [2, 3] in other waste substances, particularly shale, and its deficiency has been supplemented in a variety of ways; soil, dried sewage sludge, town refuse, and other organic waste materials have all been utilized [2, 4], but in many cases the cost of transport of these materials makes the operation of reclamation uneconomical. Where direct seeding is inevitable legumes would appear to be an obvious choice. These plants have been widely and successfully used in America [5], but so far as the authors are aware no accounts have been published of the response of legumes on the waste areas of this country. Certainly no quantitative data are available.

The present paper summarizes results obtained when two varieties of clover were sown on the summit of a large ash-disposal area at Hams Hall Power-station in Warwickshire.

Materials and Methods

The two varieties of clover employed were the wild white S.184, and white S.100. The seeds were kindly supplied to us by the Welsh Plant Breeding Station. Five grass species were sown singly with each clover variety: brown bent/616; S.143 cocksfoot; S.59 red fescue; S.23 peren-

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nial rye grass, and S.50 timothy. The growth of each clover variety, however, in every case far exceeded that of grass. Thus the contribution of grass to the yields was practically negligible. The real interest of the trials concerns the performance of clover, and no further reference to the grass species will be made in this account.

The seeds were inoculated in July 1954 and sown in plots of approximately one-hundredth of an acre, on the summit of an ash-tip adjacent to the soil and sludge plots described in [4]. The rate of sowing was 3 lb. of clover seed per acre. Each plot received a single initial dressing of a N.P.K. fertilizer at the rate of 3 cwt. per acre. Two treatments were employed. One series of plots consisted of bare ash cultivated to a depth of about 9 inches. These are termed *ash plots*. Another series which were similarly treated but later covered with approximately 2 inches of fine soil are referred to as *ash-plus-soil plots*. Each treatment was in fivefold replication, involving in all twenty plots. The clover was harvested thrice, in June and July 1955 and July 1956, by cutting the plots with an autoscythe and weighing the whole of the yield from each plot. The data so obtained are expressed in tons per acre, fresh weight.

In 1956 estimates of flower-head production and seed yields were obtained for S.100 clover by the following method. Strips of uncut clover were left to flower and seed both on soil-plus-ash and ash plots when the 1956 leaf harvest was obtained. Flower density was determined by dropping a foot quadrat three times at random along each strip and recording the number of flower-heads in each quadrat. An estimate of seed production was made from a random sample of ten seed-heads from each quadrat. All the heads thus obtained from each treatment were pooled, oven-dried to facilitate seed removal from pods, and the seed weights thus obtained converted into lb. per acre.

A comparison was also made of the viability of the seeds obtained from ash plots, with a random sample of seed of the same variety supplied by a seed merchant. Replicate samples of seeds from both sources were germinated in batches of twenty, on moist filter paper in Petri dishes, in an incubator at 20° C. The percentage germination was recorded 14 days later.

In 1956 samples of S.100 clover leaves were analysed for crude protein, phosphate, calcium, potassium, and vitamin-A content. Total nitrogen was determined by the micro-Kjeldahl method, and converted to crude protein by the factor 6·25. Phosphate, calcium, and potassium determinations were made on a wet acid digestion prepared according to Wolf [6]. Phosphate was estimated colorimetrically after Wolf [7]. Potassium and calcium were determined by the flame photometer; the special procedure of Hemingway [8] for the removal of interfering phosphate ions was employed in the calcium determinations. Vitamin A was determined as carotene and expressed as milligrams per 100 gm. dried plant tissue, after Guilbert [9].

Some of the field and laboratory determinations were also made on S.100 clover samples obtained from two further sites: Copt Heath Farm, Warwickshire, and Meaford Generating Station, Staffordshire, waste-heaps. The farm clover was obtained from crops sown with seed also

supplied by the Welsh Plant Breeding Station, which was put down in May 1955 at the rate of 3 lb. per acre, along with 3½ lb. per acre of rye grass. This clover was treated in October 1955 with phosphate and potash fertilizer at a rate equivalent to 3½ cwt. P_2O_5 and K_2O per acre. The Meaford clover was sown in plots, seeded direct on the surface of a drained ash-pond in September 1955. Three treatments were employed: ash alone, ash with a N.P.K. fertilizer at the rate of 2–3 cwt. per acre, and ash with a dressing of liquid sewage.

Results

The results obtained in the three harvests in 1955 and 1956 are shown in Table 1.

June 1955 harvest. The yields from the S.184 clover were much lower

TABLE 1. *Yields Expressed as Tons per Acre, Fresh Weight*

Date of harvest	*Treatment*	*Mean yield (from 5 plots)*		*Statistical significance*	
		S.100 clover	*S.184 clover*		
June 1955 .	Ash+soil	5·78	1·98	T. Value	2·51
	Ash alone	4·74	0·70	" " for P = 0·05	2·36
				" " " P = 0·01	3·36
July 1955 .	Ash+soil	4·38	1·36	L.S.D. P = 0·05	0·64
	Ash alone	5·14	1·98	L.S.D. P = 0·10	0·53
July 1956 .	Ash+soil	5·49	3·09	L.S.D. P = 0·05	0·71
	Ash alone	6·18	2·85	L.S.D. P = 0·10	0·58
Total (3 harvests)	Ash+soil	15·65	6·43	L.S.D. P = 0·05	2·06
	Ash alone	16·06	5·53	L.S.D. P = 0·10	1·69

than those produced by the S.100 variety (See also Figs. 1 and 2, Plate 3). The results obtained suggest that S.184 is a slower starter than S.100 and in all probability had not established itself when the first harvest was obtained. In contrast quite remarkable results were obtained with S.100 on ash and the performance of this variety on ash-plus-soil and ash have been compared by the T test, which indicates that the ash-plus-soil plots gave significantly higher yields in the early stages of establishment.

July 1955 harvest. The data for both treatments (ash-plus-soil and ash) and varieties were pooled and the significant differences were calculated for P = 0·05 and P = 0·10. As the objects of the experiment were to compare clover with clover, and soil with ash, this treatment seemed both appropriate and valid.

The results indicate that the S.100 clover was far superior to the S.184 on both ash-plus-soil and on ash. When these treatments are compared it is apparent that the S.100 clover on ash was significantly superior to that on ash-plus-soil at the P = 0·05 level. The corresponding difference for the S.184 variety, although in the same sense, was not quite significant for P = 0·05.

July 1956 harvest. Here again the S.100 clover outstripped the other

variety in yields from both ash-plus-soil and ash but the difference between the ash-plus-soil and ash treatments was not significant at the $P = 0.05$ level for either clover, although nearly so for the higher yield of S.100 clover on ash.

The total performance (three harvests) showed no significant difference between ash-plus-soil and ash, for either clover variety. The S.100 variety, however, produced a much greater total weight of leaf material (see also Fig. 2, Plate 3) than the S.184 variety, on both ash-plus-soil and ash.

Both varieties of clover produced an abundance of nodules on ash as well as on ash-plus-soil (Fig. 3, Plate 3). At the completion of the first season the clover roots had penetrated approximately one foot into the ash.

Flower-head and seed production. The values for density of flower-head production of S.100 clover, obtained by the method described

TABLE 2. *Flower-head Production. S.100 Clover, 1956*

Number of flowering heads (means of 15 quadrats)		
Hams Hall		
A *Ash plots*	B *Ash-plus-soil plots*	*Copt Heath Farm* C
62·6	54·1	51·4

T values: A.B = 0·9. A.C = 1·0. B.C = 0·2.

above are given in Table 2, comprising measurements made at Hams Hall ash and ash-plus-soil plots and from a field of clover at Copt Heath Farm. T-test analysis of the data for the three treatments taken in pairs: A.B, A.C, and B.C, indicated that there was no significant difference in flower-head production among them.

The yields of seeds produced from the Hams Hall (ash plots) and Copt Heath Farm samples, expressed as lb. per acre, were 101 and 160 respectively.

Seed viability. In August 1956 random seed samples of S.100 clover were harvested from Hams Hall, and compared in germination tests with seed from a sample of the current year's certified stock supplied by a seed firm. The percentage germination of the seeds from these two sources was respectively 79·5 (mean of ten tests) and 71·2 (mean of five tests). The two sets of data were analysed by the T test, which showed no significant difference between the values.

Chemical composition. The various clover-leaf analyses are summarized in Table 3. Significant differences have been calculated where possible. Hams Hall data concern 2-year-old plants whereas those for other samples refer to plants half that age. As might be expected, the content of protein and phosphorus was less in the older plants. On the other hand the Hams Hall samples contained more calcium than all others except those from the Meaford ash-plus-N.P.K. plots.

The figures for potassium are interesting. The farm samples (Copt

Heath) contained the highest amount of potassium. Addition of potassium to Meaford ash has indeed raised the content of this nutrient in the leaves, but it is still considerably below the Copt Heath figure. It is possible that the high calcium content of the ash is sufficient to hold the potassium content of the leaf below the normal level even when extra potassium is added in a fertilizer. The low values from Meaford ash certainly support this hypothesis. Sewage manures are known to be deficient in potassium and the potassium figure for leaf from the Meaford ash-plus-sewage plots reflects this. On the other hand phosphorus from sewage is readily available for plants, and there is thus no significant

TABLE 3. *Analyses of S.100 Clover obtained from Various Sources* (see p. 257)

	Fresh material	*Percentage of dry matter*				
	Moisture %	*Crude protein* %	PO_4 %	Ca %	K %	*Carotene mg./100 gm. dry matter*
Copt Heath Farm	81	22·50	1·02	2·12	2·85	23
Hams Hall, ash-plus-soil	80	18·71	0·82	2·43	1·35	24
Hams Hall, ash alone	83	17·32	0·90	2·55	1·27	25
Meaford, ash + N.P.K.	79	22·50	0·98	2·50	2·10	19
Meaford, ash alone	81	21·25	1·20	2·25	1·50	19
Meaford ash + sewage	81	22·81	1·06	2·00	1·45	23
L.S.D.		0·18	0·11	0·13	0·30	..

difference between the phosphorus content of the plants from the Meaford ash-plus-N.P.K. and ash-plus-sewage plots. The very low potassium values for the Hams Hall samples is probably the resultant of two effects, ageing and high-calcium ash. However, the clover plants of both varieties from all sources were quite normal in appearance for all treatments; no deficiency symptoms have been observed. Carotene values for all the samples are at expected levels. They correspond to the carotene figures given for the late-harvest stage of white clover published by Olsson [10]. This investigator has reported detailed investigations on the amounts of this pro-vitamin for a number of meadow plants including grasses, clovers, and lucerne. It appears that there was a steady fall in the carotene content of clover, from values of the order of 53·7 mgm. per 100 gm. dry weight in May, to values as low as 26·6 as the season proceeded towards July and August; the mean value of 22 for the same period, in the analyses reported here, is of the same order.

Discussion

A 2-year experiment using two varieties of white clover thus indicates that both may be established directly on the surface of an ash tip some

45 feet in depth. The plant roots penetrated freely and deeply into the ash, developed abundant nodules, and showed no signs of matting, a feature which has been noted in the case of certain grasses and weeds growing in a similar situation (Rees and Cox, unpublished data).

The rate of growth and total fresh weight yields of one variety (S.100) far exceeded those of the other variety (S.184) but it remains to be seen for how long this superiority can be maintained. In view of this difference in performance between varieties, the S.100 was selected for comparison with results obtained in normal farming practice. Williams and Evans [11] in their study of the effects of different manurial treatments on the productivity of white clover obtained a total yield of 0·85 tons of air-dried fodder per acre over a period of 3 years (1928–30). The yields for the first three harvests in the present investigation greatly exceed this figure, viz. 3·13 and 2·73 tons dry weight of foliage per acre for ash-plus-soil and ash treatments respectively. Chemical analyses for some of the more important nutrients show that second-year clover leaves from ash plots contained slightly lower amounts of all the constituents determined, except carotene, when compared with first-year leaves of the farm crop. Williams and Evans [11] and Williams [12] have pointed out that protein content of clover varies considerably throughout the season, reaching its highest peak in spring and decreasing to a minimum in July and August. A more critical study of leaf-protein levels throughout the season is necessary to ascertain whether maximum protein levels vary in this way among the various treatments studied. There was little difference in protein values between the samples from Copt Heath Farm and Meaford for first-season leaves. If indeed the levels of nutrients in plants grown on ash do vary from those in farm-produced clover, there is nevertheless no evidence of any nutritional disorders among clovers grown on ash.

There was no significant difference between treatments as regards flower-head production, but as might have been expected the first-year plants at Copt Heath Farm produced a greater yield of seeds as compared with second-year plants from Hams Hall ash plots.

Mention has already been made of problems of aluminium and manganese toxicities which may be encountered among certain crop plants grown on Hams Hall ash [1]. No evidence of harmful effects of either of these metals was observed in white clover. It is of interest to note in this respect that Löhnis [13] has reported a strong tolerance of this species to excess manganese, which she attributes to a weak absorption of this metal by clover plants. Oats, mustard vine, and mangolds owe their tolerance to manganese to a similar reason. Some of these plants, however, are affected by the aluminium in ash. It seems that both the varieties of clover used in this investigation are immune from harmful effects of high manganese and high aluminium alike. It is also of interest to note that the Rhizobium associated with their nodules is also apparently unaffected by high levels of these elements.

The results of this work suggest that clover may be a valuable means of covering large areas of ash deposits, especially in areas where the local soil or overburden is not readily available or is of poor nutrient status.

Once established this crop does not require any manurial treatments and in time will itself add considerable organic matter to the ash medium. In a matter of months from seeding the young clover plants completely controlled any wind removal of ash from the drying surface. This method of stabilizing the ash surface could well be employed annually to cover fresh surfaces of an ash-disposal site as tipping and levelling proceed. Clover and other legumes might well be used as a forerunner of grass, for the use of such sites for playing fields or for grazing.

Acknowledgements. The authors wish to thank Professor E. J. Maskell for his comments and encouragement; Professor E. T. Jones of the Welsh Plant Breeding Station who supplied the seeds; Mr. L. E. Evans of Copt Heath for kind permission to use his clover crop; the Central Electricity Authority, Midland Division, and Research Council for successive research grants towards travelling expenses and apparatus involved in the work; and finally Messrs. J. Paxton and F. O. Brown, successive Station Superintendents at Hams Hall 'A' Station, for much assistance in the field work.

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FIG. 1. General appearance of the clover plots, June 1955

FIG. 2. Close-up of one block. S.100 clover in background: S.184 in foreground

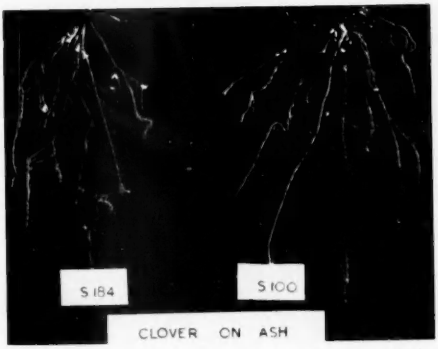

FIG. 3. Nodule development on both clover varieties

CORRIGENDUM

In the paper by V. A. Oyenuga in Volume XXV, p. 250, line 6 from bottom, for 12 weeks after sowing *substitute* 11 weeks after sowing and again 10 weeks later.

FURTHER NOTES ON THE DEVELOPMENT OF THE SERERE HERD OF SHORTHORNED ZEBU CATTLE

P. N. WILSON

(*University College of East Africa, Kampala, Uganda*)[1]

Summary

The policy of the Serere herd is traced between 1950 and 1954.

The liveweight gains for both sexes are discussed. For the period 1943–54 the average weight of yearling cattle was 218 lb. (males) and 195 lb. (females). The mature weights of beasts (at 6 years) averaged 798 lb. (males) and 622 lb. (females).

The birth weights of calves showed seasonal variation, closely correlated to the bimodal mean annual rainfall curve for Serere Station. The mean birth weight during the month of peak rainfall, April, was 39·3 lb., and towards the end of the severe dry season, February, it was 36·1 lb.

The birth weight of calves increased significantly up to the third calf born, and did not vary significantly thereafter. There is no evidence for any marked decrease in calf weight after the tenth calf born, as previously claimed.

There was a marked seasonal incidence in calving rate. The deduced conception-rate curve is mono-modal, and in general varies inversely with the mean monthly rainfall. This resulted in the greatest calf-drop occurring at the beginning of the long dry season and the lowest immediately before the onset of the long rains.

No correlation between weight of dam and weight of calf was shown when calves from immature first- and second-calvers were excluded.

Data for calf mortality are presented. East Coast Fever was responsible for the largest number of pre-weaning deaths, but the mortality due to this disease has steadily decreased during the period 1950–4. Male calf mortality was significantly higher than female, and there were large differences in the calf mortality percentages for the different herd bulls.

Most of the animals in the Serere herd are coloured (red and brown). The number of black animals is decreasing. No herd bulls so far employed have exhibited a high degree of prepotency for any particular colour-complex.

The increase in butterfat percentage with advancing stage of lactation was approximately linear, the range being from 4·7 per cent. at the first month of the lactation to 7·1 per cent. at the tenth. The mean butterfat percentage was 5·7 per cent.

THE amount of detailed information on the productive value of Zebu cattle reared under East African conditions is still relatively small. The information which does exist is often difficult to interpret since the environmental conditions differ widely from one research station to another, and management changes are not infrequent. In addition, the Zebu breed is extremely varied in type, and an adequate classification of the breed into regional types is only just being attempted (Mason and Maule, unpublished).

Williams and Bunge [1] published the results obtained from the first ten years' work with livestock at Serere Experiment Station, Teso, Uganda. The present paper aims at tracing certain developments which have occurred between 1950 and 1954, and also deals with some aspects

[1] Now at Imperial College of Tropical Agriculture, Trinidad, B.W.I.

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of animal husbandry and production which were not covered in the previous paper. For easy reference, the present work is based on the same plan as the paper by Williams and Bunge.

History of the Serere Herd since 1950

The Serere herd has remained closed since 1950 with the exception of the introduction of two beef-type bulls. These introductions were made in October 1953 and one bull, Odiyo, is at present serving.

Up to August 1951 three herds were kept at Serere managed under the following conditions:

1. *Milked-out herd.* Calves bucket-fed. Cows milked twice daily by hand. Supplementary feeding given.
2. *Suckled herd.* Cows milked twice daily by hand with calves at foot. Calves suckled. Supplementary feeding given.
3. *Free-range herd.* Cows never milked. Calves run with dams the whole time. No supplementary feeding given.

In August 1951 the management of the second herd was modified. The cows were milked out each morning at 8·00 a.m. with calf at foot, and the calves ran with their dams for the rest of the day, but were separated and housed independently at night and until milking the following morning. This method, now designated the Semi-range system, was adopted to ensure that the calf received a minimum of one-half of the daily production of its dam. It is now departmental policy to recommend this system of management in the District and the new Semi-range herd is a demonstration herd for African visitors to Serere.

Up to 1950 the Serere cattle were managed under conditions which aimed at production with the maximum economy of foodstuffs and milk. From 1951 the emphasis was changed to enable the maximum production which good management and environment would permit. The production and dry-season rations to all stock were markedly increased, and the amount of milk fed to the bucket-fed calves rose to a level of 150 gallons of whole-milk equivalents per calf up to weaning. Individual attention and special high-plane feeding was given to animals which showed promise as potential milkers or breeding stock. This change in the management must be borne in mind when the liveweight-increase data and milk records are considered in later sections.

The policy in regard to the Free-range herd was modified in September 1953 when it was decided to build up this herd into a nucleus breeding herd for beef stock. The bull Binyom was replaced by the newly acquired bull Odiyo, which was selected for weight and conformation. Cows of poor beef conformation were excluded from this herd.

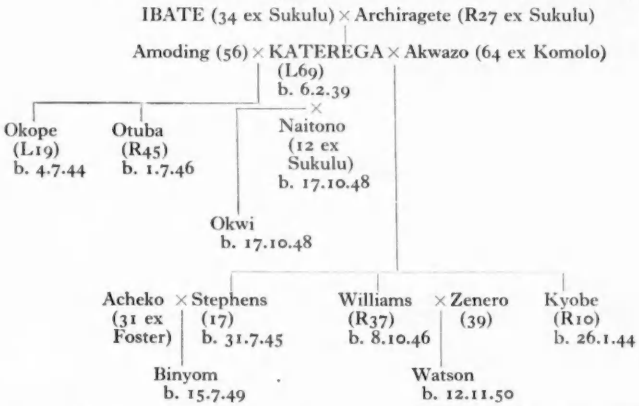
Up to 1952 all cattle at Serere, with the exception of the Free-range herd, were kraaled at night. The original purpose of this policy was to guard against losses by theft and big game, and to provide farm-yard manure for the farm. In 1952 this practice was discontinued and instead cattle were night paddocked, so far without any loss.

Breeding Programme

The primary objective of the Serere herd is to provide information about the productive capacity of the indigenous shorthorned Zebu cattle of Uganda, and to investigate optimal methods of cattle management. The second, long-term objective of the Serere herd is to provide improved breeding stock for Teso and similar districts. So far, work has not advanced sufficiently for a programme of dispersal of animals of superior genetic value to be implemented.

The Serere herd is to be built up into a dual-purpose herd. In the first stages selection has mainly been for milk rather than for beef, as it was

TABLE 1. *Genealogy of the Katerega Line, 1940–54*



Note. The three bulls Kyobe, Stephens, and Williams, all of whom have been used extensively as herd bulls, are full sibs.
The two bulls Okope and Otuba are also full sibs, but only Okope has been used as a Serere sire.

considered that one of the limiting factors of liveweight-increase and early-maturity was the low milk supply available to the calf up to weaning. Cows in the main Milked-out herd have therefore been selected in the past mainly on the criterion of milk-yield, and in 1954 the stage was reached when no beast was allowed into this herd without achieving a mean yield of 200 gallons for the first two lactations. Cows in the Beef herd will be selected mainly on beef-type conformation, since this character might tend to be lost through low selection pressure in the Milked-out herd.

A Progeny-testing Scheme for bulls which would take into account both milk-yield and liveweight-increase has been suggested, but has not yet been implemented. Such a scheme would require a number of sub-stations away from Serere for the purpose of testing the performance of the F. 1 generation. The maximum herd strength which Serere could carry is about 500 adult stock, but it has been shown that a herd of 2,000 cows is needed to secure the maximum genetic improvement by the

progeny testing of closed herds [2, 3]. With herds of 100–200 cows the rate of genetic improvement is approximately half the theoretically

TABLE 2. *Table showing the Bulls used in the Serere Herds*

Year	*Suckled herd (started 1939, disbanded 1951)*	*Milked-out herd (started 1946)*
1939–40	Badcock	..
1940–1	*Katerega L69*	..
1941–2	*Katerega L69* Badcock	..
1942–3	*Katerega L69* Badcock	..
1943–4	Oula *Katerega L69*	..
1944–5	Oula *Katerega L69*	..
1945–6	Oula *Katerega L69*	..
1946–7	Oula *Katerega L69*	Oula *Katerega L69*
1947–8	*Kyobe R10* *Okope L19*	*Kyobe R10* *Okope L19*
1948–9	*Kyobe R10* *Okope L19* *Stephens L7*	*Kyobe R10* *Okope L19* *Stephens L7*
1949–50	*Kyobe R10* *Okope L19* *Stephens L7*	*Kyobe R10* *Williams R37* *Stephens L7*
1950–1	*Williams R37* *Stephens L7*	*Williams R37* *Stephens L7*
1951–2	..	*Williams R37* *Stephens L7*
1952–3	..	*Williams R37* *Stephens L7* *Watson*
1953–4	..	*Watson* *Williams R37*

Year	*Free-range herd (started 1947, disbanded 1953)*	*Beef herd (started 1953)*	*Semi-range herd (started 1952)*
1947–8	Badcock	..	..
1948–9	Badcock Oula	..	..
1949–50	Oula	..	..
1950–1	Oula	..	..
1951–2	Oula	..	..
1952–3	Oula *Binyom*	..	*Okwi*
1953–4	..	*Binyom* Odiyo	*Okwi*
1954	..	Odiyo	*Okwi*

Note. Bulls of the Katerega line are shown in italics.

possible value and with herds the size of the existing Serere herd it would be possible to progeny-test only two young bulls each year. The present bulls at Serere have not been subjected to any objective form of statistical progeny test, other than a comparison of the offspring of the Badcock, Oula, and Katerega lines which has led to the retention of the sons and grandsons of Katerega as the present premier herd bulls. The policy of line-breeding on the Katerega line as described by Williams and Bunge [1] is still followed at Serere with the exception, already noted, of the introduction of an outside bull for siring the 'Beef' herd. Three new bulls have been serving during the period 1950–4, all three being sons or grandsons of Katerega. Table 1 shows the genealogy of the Katerega line, and Table 2 summarizes the line-breeding programme up to May 1954.

The form of line-breeding adopted at Serere has led to animals with a fairly high coefficient of inbreeding after only four generations. If the present 'closed' policy continues, the percentage of inbreeding in the milked herds will be expected to rise. A few beasts with coefficients of inbreeding of 25 per cent. are now found in the herd.

TABLE 3. *Liveweight Gains, Serere Herd, 1943–54*

	Males (*lb.*)	*Nos.*	*Females* (*lb.*)	*Nos.*	*McDonald* (*202*) (*lb.*)
Birth weight . .	38·6	116	36·6	146	42
6 months . .	134·5	116	129·5	146	373
12 ,, . .	214·7	116	194·5	146	478
18 ,, . .	295·3	116	243·2	144	612
24 ,, . .	389·6	108	318·2	125	701
30 ,, . .	477·1	105	391·2	112	788
36 ,, . .	559·6	99	472·9	98	928
42 ,, . .	632·8	82	526·6	85	993
48 ,, . .	675·7	61	560·8	76	..*
54 ,, . .	729·0	35	559·2	68	..
60 ,, . .	746·4	24	589·6	60	..
66 ,, . .	768·8	18	594·2	52	..
72 ,, . .	797·6	12	622·1	44	..

* 1,014 lb. at 45 months of age.

Production Data

Liveweight increase. A marked improvement in earliness of maturity of the Serere cattle has been reported since 1950. This improvement must be mainly attributable to the increased rations fed to the calves and young stock, and to the better quality of the *Chloris gayana* leys now grown at Serere for the feeding of the young stock up to sexual maturity. Table 3 shows the liveweights of male and female stock at 6-monthly intervals, and these data are compared graphically with the data presented by Williams and Bunge in Fig. 1.

The male liveweight curve is normal, whereas that of the females flattens markedly between 42 and 54 months. This flattening has been

attributed by Williams and Bunge [1] to the fact that the heifers calve down for the first time at about this age.

Maximum adult weights are not reached in either sex until a very late age. The data available are insufficient to deduce the age of maximum weight with precision, since there are very few records available for stock over 72 months of age. Fig. 1 shows that the males did not reach

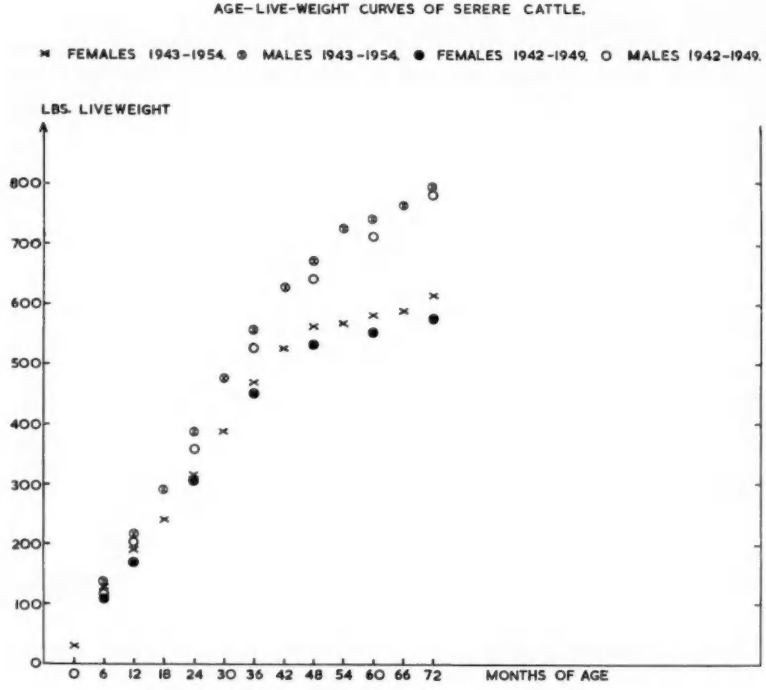


FIG. 1.

maximum weight until well past that age, whilst the females reached their maximum weights at approximately that age. The growth of both sexes was approximately exponential between 1 year and 3 years.

The heaviest beast recorded at Serere is Odio (210), a herd bull purchased in 1953, weighing 1,156 lb., in August 1954. The heaviest cow recorded is Alimo (105) weighing 857 lb. at 100 months just prior to calving down. Her weight the following month, after calving, was 781 lb.

The most outstanding example of early maturity recorded at Serere is that of the bull McDonald (202) which weighed approximately 700 lb. at 2 years of age. The weight record of this beast, which is being kept for breeding, is shown in the last column of Table 3.

Certain workers, especially French [4], argue that the indigenous Shorthorned Zebu of Uganda does not possess, and should not be encouraged towards, early maturity and large body size. The reason given is that the small, slow-growing animal is probably the most economic, in terms of output per acre, under prevailing Uganda conditions. An

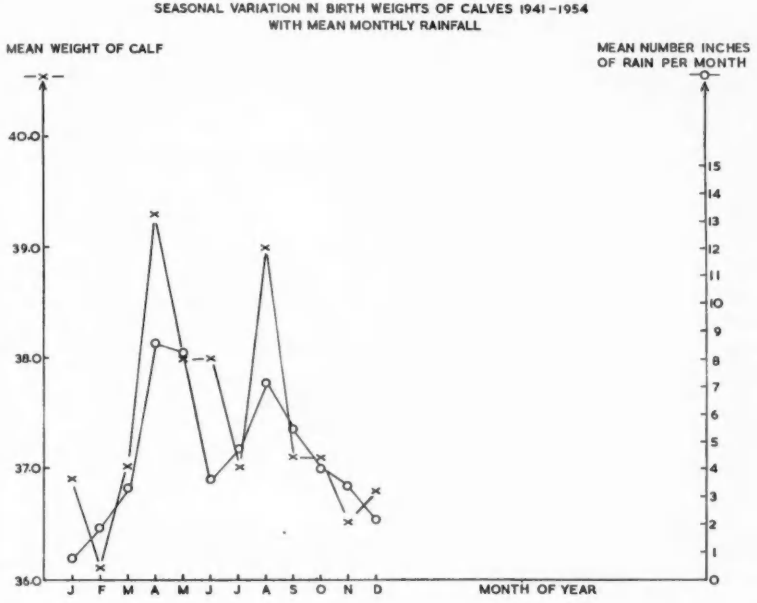


FIG. 2.

attempt to increase output per beast at the expense of output per acre would not be in the best interests of the cattle industry.

Birth Weights

(*a*) *Effect of season on birth weights of calves.* Williams and Bunge [1] stated that there was no noticeable seasonal influence on birth weight. This point has been studied in detail, and Fig. 2 shows that there was in fact a pronounced seasonal variation in mean birth weight which can be correlated to the mean monthly rainfall distribution at Serere. The bimodal distributions both possess peaks during April and August, and troughs during the months November–February (long dry season) and June–July (short dry season). The rank correlation coefficient of mean monthly calf weight to mean monthly rainfall is 0·82, which is statistically significant at the $P = 0{\cdot}001$ level. When the sexes are considered separately (thus reducing the sample size of calf weights by one-half)

the rank correlation is much more pronounced in the case of the male sex ($r = 0{\cdot}82$) than the female ($r = 0{\cdot}30$).

It would be interesting to determine whether this seasonal difference in calf weight is partly or wholly attributable to cows calving in the rains carrying their calves for a slightly longer gestation period than cows calving during the dry periods. Unfortunately conception dates are not readily available at Serere, and so the data do not enable this important point to be resolved.

TABLE 4. *Effect of Advancing Lactation on Birth Weights of Calves*

Number of lactation	*Number of calves recorded*	*Mean birth weight of calf (lb.)*
1st	124	34·5
2nd	114	36·9
3rd	97	38·5
4th	69	38·7
5th	58	39·5
6th	52	38·7
7th	40	39·0
8th	31	38·5
9th	25	40·6
10th	17	36·5
11th	15	35·3
12th	5	40·4
13th	2	28·5

(*b*) *Effect of advancing lactation on the birth weights of calves.* Table 4 is compiled from the records of all calves born at Serere between 1940 and 1954 whose birth weights have been recorded within 12 hours of the actual birth.

The contention of Williams and Bunge [1] that birth weight increases up to the third calf born, is supported, but the extra data now available do not appear to agree with these workers' suggestion that there is a drop in calf weight after the tenth calf born. The irregularity of the mean birth weights after the eighth calf is probably accounted for simply by the paucity of records after this stage. Significant differences were shown between the two sexes ($P = 0{\cdot}10$) and between the mean birth weights of the first and second, and second and third lactations ($P = 0{\cdot}01$).

(*c*) *Maximum and minimum birth weights of calves.* The records remain as reported by Williams and Bunge [1].

Heaviest male: 57 lb. Heaviest female: 61 lb.
Lightest male: 24 lb. Lightest female: 21 lb.

(*d*) *Effect of season on the calving rate.* Fig. 3 shows the number of calves born in the different months of the year. The records are taken from 825 calvings and they suggest that the calving distribution is monomodal around the peak months September–November. During this quarter of the year, 272 of the total calvings have occurred, i.e. 33·0 per cent. During the half-yearly period June–November inclusive, 502

calvings have been recorded, compared with 323 during the other half of the year. Assuming that the absence of a seasonal calving distribution would give an expectation of 412·5 calves in each half-yearly period, the χ^2 has a value of 26·5, which is significant at the P = 0·01 level.

These results agree with the provisional findings of J. Ross (unpublished F.R.C.V.S. thesis, 1954) for Teso District African-owned cattle, and similar trends have been recorded for sheep at Busoga Farms

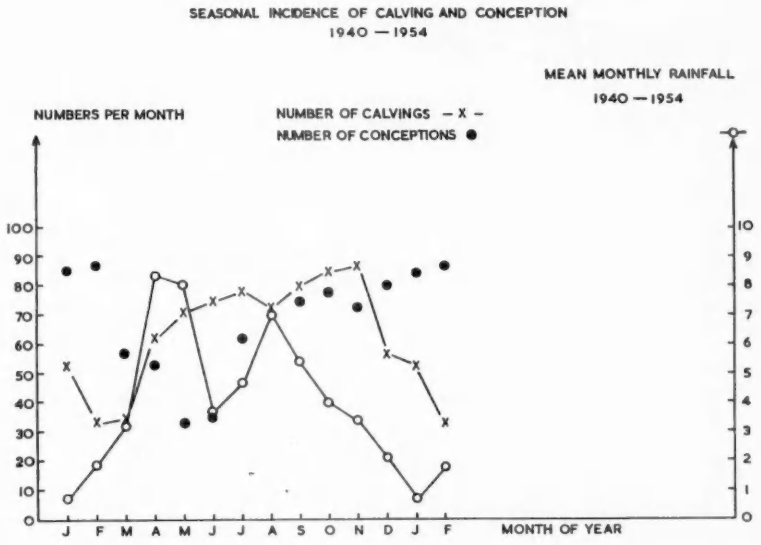


FIG. 3.

and Mbarara Stock Farm by D. H. L. Rollinson (personal communication), although the data supplied by these workers are insufficient for statistical significance to be obtained. They are also in complete agreement with the findings of Barrett and Bailey [5] in Kenya.

Fig. 3 shows that the seasonal distribution was such that the majority of calvings occurred in the half-yearly period prior to the dry season, with peak calvings one or two months before its commencement. This would allow the calves to be reared, and some of them weaned, during the long dry season January–March when the climatic conditions are optimal, and when the general level of herd productivity (as judged by liveweight gains and milk production) is at its highest.

(*e*) *Effect of the weight of the dam on the weight of calf.* Table 5 presents data for the weight of the dam after calving and the weight of the calf, from the records of 317 calvings. The weights of the dams have been grouped into a contingency table, the indiscrete variable being arbitrarily fixed at 25 lb. liveweight.

Table 5 shows that there was no evidence of a positive linear regression of liveweight of dam with the weight of the calf born, although there was a significant tendency for the calves from dams of less than 625 lb. liveweight to be smaller than calves from dams of over 625 lb. liveweight. The mean weight of calves from dams of less than 625 lb. was 35·7 lb., and the mean weight of calves from dams over 625 lb. was 37·9 lb., the difference between the means is significant at the $P = 0{\cdot}01$ level, $t = 3{\cdot}16$.

TABLE 5. *The Effect of the Weight of the Dam on the Weight of the Calf at Birth*

Arbitrary grouping of dam weight (lb.)	*Mean dam weight of group*	*Mean calf weight*	*Calf weight variation from weighted mean*	*Number of observations*
Less than 475 .	453·0	37·5	+0·2	7
475–499 . .	489·9	33·7	−3·6	11
500–524 . .	518·5	35·1	−2·2	11
525–549 . .	540·3	36·3	−1·0	24
550–574 . .	564·7	36·7	−0·6	26
575–599 . .	589·7	34·8	−2·5	36
600–624 . .	612·7	36·9	−0·4	50
625–649 . .	636·9	38·5	+1·2	52
650–674 . .	662·8	36·8	−0·5	36
675–699 . .	688·9	38·7	+1·4	26
700–724 . .	708·8	42·1	+4·8	17
725–749 . .	740·9	39·7	+2·4	10
750 and over .	772·2	36·7	−0·6	11

The figures presented in Table 5 include data obtained from first- and second-calvers. As it has been shown under section (*b*) that the weight of the calf increases up to the third calving, and as it has also been shown in Fig. 1 that the liveweights of the females increase up to 72 months old, it was thought desirable to eliminate the data for all first- and second-calvers from this study. Of the 317 calving records presented in Table 5, 145 were obtained from either first- or second-calvers. These 145 records have been omitted from a further study which showed that there was no significant difference between the mean of calves dropped from small or large third and subsequent calvers. The means were 36·8 and 38·0 lb., and $t = 1{\cdot}21$ (non-significant).

Sex Ratios of Calves Born

Williams and Bunge [1] reported a sex-ratio of 48 per cent. heifer-calves to 52 per cent. bull-calves during the period 1940–9 inclusive. During the subsequent period, 1950–4 inclusive, 372 calves have been born, of which 51·9 per cent. were female and 48·1 per cent. male, a reversal of the previously recorded and normal trend of a calf-drop weighted in favour of the male. The combined data do not provide any evidence for assuming a secondary sex-ratio biased in favour of either sex.

Calf Mortality

There has been a gratifying decrease in the incidence of calf mortality up to the weaning stage in the period 1950–4 compared to the period 1940–50. The calf mortality figure of 18 per cent. recorded by Williams and Bunge has been reduced to 13·9 per cent. Table 6 summarizes the causes of the calf mortality as far as they are known. Facilities for post-mortem examination do not generally exist at Serere.

Table 6 shows that there has been a very marked decrease in deaths due directly or indirectly to East Coast Fever. This must be partly attributed to the use of sulpha-pyridine during the period 1950–4 which would suppress coincidental bacterial infections, and partly also to the

TABLE 6. *The Chief Causes of Death before Weaning 1940–9 and 1950–4*

Cause of death	*1940–9*	*1950–4*	*Total*	*Percentage*
East Coast Fever and coincidental infections following a clinical attack of E.C.F.	52	7	59	38·1
Not diagnosed or unrecorded	24	31	55	35·5
White scour	7	2	9	5·8
Premature or weak at birth	5	2	7	4·5
Blackquarter	1	5	6	3·9
Hoven	4	1	5	3·2
Injuries—mechanical	2	1	3	1·9
Pneumonia	1	1	2	1·3
Enteritis	2	0	2	1·3
Other miscellaneous causes	6	1	7	4·5
Total	104	51	155	100·0

very high level of calf-feeding which is practised, under a system in which the calf is given approximately 150 gallons of whole-milk equivalents up to weaning. The Serere practice in regard to the prevention of mortality from tick-borne diseases, especially East Coast Fever, is in conformity with the present general policy for Uganda as laid down by the Veterinary Department. This policy is to control, but not to eradicate, the tick population so that the young stock contract East Coast Fever at an age when they are capable of recovering and acquiring complete or partial immunity to subsequent infection. This policy is carried out by dipping the adult stock when the tick population has reached a level when a few ticks can be observed feeding on the stock. Gamatox dip has been in use since September 1953; previously arsenical dips were employed. Unweaned calves are neither dipped, nor sprayed. There has been an increase in the number of deaths attributable to Blackquarter since 1950, and young stock are now given routine inoculations against this disease. A large number of deaths recorded as being due to unknown causes refer to bucket-fed calves which grew weak and died through failure to take to the system of bucket feeding. It is possible that, in some Zebu calves, there is a failure of the mechanism by which the œsophagal groove should close during the ingestion of milk, and that instead of passing to

the omasum, the milk taken from the bucket passes directly into the rumen and reticulum. Whole milk fed to bucket-fed calves at Serere is mixed with a mineral mixture and supplied to the calf at blood temperature.

Table 7 gives the mortality of calves classified in monthly age groups.

It will be seen from Table 7 that up to the weaning stage there were three periods of high calf mortality:

1. A peak mortality period in the first month, representing deaths due to a variety of causes—premature births, genetic defects, failure to feed, &c.

TABLE 7. *Sex Differences and Age Incidence in the Mortality of Calves 1940–54*

Age, months	*1940–9 (Williams and Bunge [1])*		*1950–4*		*Total*	*%*
	Male	*Female*	*Male*	*Female*		
Less than 1 . .	9	8	9	3	29	18·8
1–2 . . .	6	3	4	3	16	10·3
2–3 . . .	6	8	3	2	19	12·3
3–4 . . .	12	5	3	0	20	12·9
4–5 . . .	12	8	0	1	21	13·6
5–6 . . .	6	5	4	3	18	11·6
6–7 . . .	2	2	3	2	9	5·8
7–8 . . .	1	1	1	1	4	2·5
8–9 . . .	1	2	2	3	8	5·1
9–10 . . .	5	2	2	2	11	7·1
Totals . .	60	44	31	20	155	100·0

2. A second period of high mortality between 3 and 6 months, attributable mainly to deaths from East Coast Fever.
3. A third period associated with the difficulties of weaning at 9 months. All animals suffer a 'post-weaning check' at this time, and a few die

The highest mortality rate occurred during the first month after birth. This picture is similar to that reported by Lovell and Bradford Hill [6] for *Bos taurus* cattle in Britain, where 57 per cent. of the total calf mortality occurred in the first month of life. In the survey conducted by Lovell and Bradford Hill the chief cause of death was *Coli bacillosis* (White scour), which accounted for approximately one-half of the total calf mortality. In the Serere herd, although White scour was responsible for only 5·8 per cent. of the total deaths, it was nevertheless the chief cause of death apart from East Coast Fever.

Table 7 shows that 58·7 per cent. of the calf mortality occurred with the male calves. This results in the sex-ratio of the weaned young stock being strongly biased in favour of the females.

Table 8 presents figures for the mortality of calves sired by the different herd bulls in use at Serere. The breeding programme and a list of herd bulls has already been set out in Tables 1 and 2.

The data for the two bulls Watson and Okwi are insufficient to assess or compare their calf mortality figures with those of the other bulls. Although there has been a general decrease in calf mortality during the last 5-year period, it is disquieting to note that the three bulls in use in 1954 had a provisionally higher mean calf mortality than the mean for all Serere bulls; 21·8 per cent. compared with the mean for all bulls of 16·9 per cent. This suggests that selection pressure against calf mortality in the Serere herd has been low, but with changes in the system of calf management between the offspring of different bulls it is not possible to estimate the heritability of calf mortality.

TABLE 8. *Calf Mortality by Bull Groups to 31 December 1954*

Bull	*Number of calves sired*	*Number of dams served*	*% Calf mortality*	*Years in use*
Badcock . .	123	48	27·6	1939–49
Watson . .	19	19	26·3	1952–4
Okwi . . .	23	14	21·7	1952–4
Williams . .	81	42	17·3	1949–54
Katerega . .	217	53	16·1	1940–7
Stephens . .	117	53	11·1	1948–53
Oula . . .	84	47	8·3	1943–53
Kyobe . .	81	49	7·4	1947–50
Mean . .	93·1	40·6	16·9	

Colour Distribution of Serere Herd

The cattle at Serere are mainly coloured. 57·9 per cent. of the 306 cattle for which colour records are available fall into this group, compared with 34·9 per cent. predominantly white and 7·2 per cent. mixed (white and coloured).

The actual colour-complexes represented, together with the number of stock falling in each group, are: white, whitish 107; red, reddish 89; black, blackish 49; brown, brownish (and brindle) 39; brown and white 9; red and white (and roan) 8; black and white (and blue) 5. No marked prepotency for colour has been exhibited by any of the Serere bulls for which colour records are available. A large proportion of black stock were present in the original introductions of foundation stock to Serere, and this proportion has steadily decreased. No black bulls have been used at Serere for breeding.

Several workers [7, 8, 9] have shown that a white, yellow, or red coat with a smooth glossy texture is best for minimizing the adverse effects of solar radiation, and that the black coat has the highest mean absorptivity percentage. Although coat-colour has not been regarded as sufficiently important to include it as a factor to select for or against, the fact that there has been a steady decrease in the black-coloured cattle at Serere may well be advantageous. Black cattle are common in Teso District, where between 25 and 30 per cent. of the cattle population are black or blackish [10].

Variations in Butterfat Percentage at Different Stages in the Lactation

Williams and Bunge [1] stated that butterfat testing commenced in August 1949. Records for 1949–53 depended on the result of single test-samples, and as a result the variation in percentage recorded for a given cow from one month to another was sometimes as high as 3 per cent. Some of this variation must be ascribed to faulty sampling technique and lack of replication, and it is now the practice at Serere to retest any cow

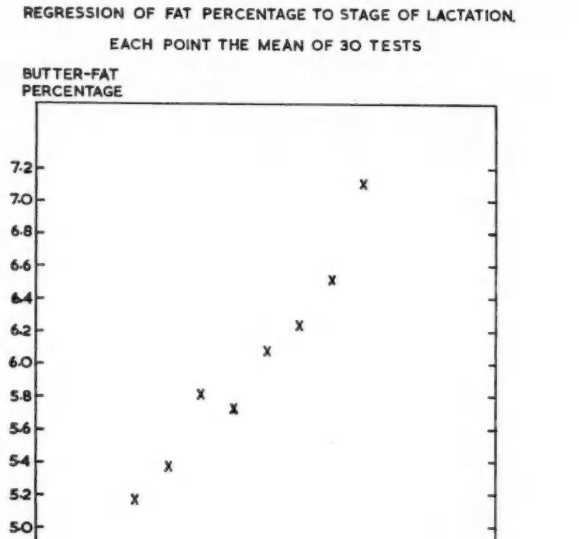


FIG. 4.

which shows a variation of more than 0·5 per cent. in butterfat percentage between one month and the next.

Using data obtained under this new system from January 1953 to March 1954, the butterfat curve shown in Fig. 4 has been obtained. It is seen that the percentage of butterfat increased from a mean value of 4·69 per cent. at the first month to a mean value of 7·12 at the tenth month of lactation. The increase is approximately linear. Regression coefficients have not been computed in view of the small number of data at present available. The curve cannot be extrapolated to day-of-calving, since no routine tests are carried out on colostrum milk. The figures are in close agreement with data available from twenty-five cows at Kawanda Research Station, Uganda, which showed an increase in butterfat percentage from 4·4 per cent. at the first month to 7·9 per cent. at the eighth month of the lactation [11].

The lowest butterfat test recorded since January 1953 is 3·7 per cent. obtained from cow No. 117 at the end of the first month of her lactation, and the highest is 8·5 per cent. obtained from cow No. 143 at the beginning of the tenth month of her lactation. The lowest and highest tests are therefore at the beginning and end of the lactation respectively, as would be deduced from the butterfat curve in Fig. 4. The mean butterfat percentage for the period is 5·70 per cent.

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Footnote

Since the date of writing this paper (January 1956) further changes in the management of the Serere herd have occurred, and this paper does not reflect current practices.

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FERTILIZER EXPERIMENTS IN CYPRUS. I. EXPERIMENTS WITH POTATOES, COTTON, AND ONIONS

P. A. LOIZIDES

(*Department of Agriculture, Cyprus*)

Summary

A short account of the soils, climate, and crops of Cyprus is given.

The response of potatoes to nitrogen fertilizers was significant in 20 out of 22 experiments and to superphosphate in 14 out of 20 experiments. The apparent interaction of these fertilizers was positive in all experiments, but it rarely reached significance. The effect of nitrogen and phosphorus fertilizers in most experiments was confined to the single dressing which supplied about 0·5 cwt. N or P_2O_5 per acre. In some experiments the increase to a double dressing of N caused a significant reduction. The results are discussed from the point of view of the most suitable dressing to be applied to the potato crop.

In twenty-three experiments potassium fertilizers failed to raise yields of potatoes and in three they caused a significant reduction. The causes of lack of response to potassium are discussed.

In one out of two experiments animal manure caused a significant increase in yield of potatoes. Differences in time of application had no effect on the yields of potatoes grown with nitrogen fertilizers.

In two experiments, potatoes receiving sodium nitrate or Nitrochalk gave similar yields to those receiving the same amount of N in the form of ammonium sulphate.

In one experiment a significant response of the yield of onions was obtained to ammonium sulphate but not to superphosphate.

In two out of three experiments ammonium sulphate and superphosphate each had a significant effect on the yield of seed cotton, and in one there was an indication that the two together had an effect on lint length.

THE aim of this series of papers is to present the results of a number of fertilizer experiments carried out by the writer during the war and, particularly, the post-war period, mainly with potatoes, cereals, and vines, in various parts of Cyprus. These are the only fertilizer experiments carried out in the island, with the exception of the long-term experiments with cereals described by Littlejohn [1] and three experiments with cotton, all carried out before 1939 at the experimental farm of the Agricultural Department at Morphou. Since conditions in Cyprus are markedly different from those of western Europe, a short account of the soils and climate of the island is given, so that the significance of the results given in these papers may be better appraised.

Climate, Soils and Crops

Cyprus is an island in the eastern Mediterranean covering an area of 3,600 square miles. It is traversed by two mountain ranges; the northern range, rising to over 3,000 feet, consists mainly of Jurassic limestone and dolomite, while the more extensive southern range, rising to 6,400 feet, consists of basic to ultra-basic rocks from dolerite to pyroxenite and peridotite and is almost completely surrounded by low foothills of pre-

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dominantly basic lavas. Between the two ranges is the central plain, the main agricultural area of Cyprus.

Mean annual rainfall varies from around 14 in. in the central plain to 20 in. over much of the coastal area, rising to 36 in. or over in the higher parts of the southern range. It falls predominantly in winter, December–February being the main rainy season, while the period June to September is practically rainless. Winters are cool, temperatures below freezing often being recorded in the plains while snow may lie on the higher peaks until May or June. In the summer, shade temperatures often exceed 100° F. Thus the climate of Cyprus belongs to an extreme Mediterranean type.

No soil survey of Cyprus has been carried out. A report on the soils of Cyprus has recently been prepared by Osmond [2], who also gives a short account of the geology, based on Henson, Browne, and McGinty [3], and of certain topographical features of the island. His classification of the soils of Cyprus is based on Kubiena's system.

In the short account of the main agricultural soils of Cyprus that follows, it has been found difficult to follow Osmond's classification in every detail. This classification is admittedly tentative and there are certain soils that cannot be conveniently fitted in to any of the types recognized by Osmond.

Alluvial soils, formed on recent water-borne deposits. Organic-matter content is usually around 1 per cent. but may rise to 2 per cent. under favourable conditions. Lime content varies, depending on the parent material, from zero to over 50 per cent. Texture is variable with the heavier soils (clay-loams and clays) predominating. Large areas of these soils receive irrigation from flood waters in winter and spring.

In Kubiena's classification they come under the Division of demi-terrestrial soils. This term is probably appropriate in certain areas where there is seasonal waterlogging or a high water-table in winter and spring, but seems inapplicable to the majority of the soils where the water-table is low and flood irrigation does not add more than a few inches of water.

Rendzinas. Light-coloured, calcareous soils formed on soft highly calcareous solid rocks or calcareous colluvium or alluvium. Unlike those of Europe, their content of organic matter is low, not exceeding 1 per cent. in cultivated land. Osmond recognizes a number of rendzina types but probably the most extensive are mull or mull-like rendzina. Clay loams and clays predominate.

Terra rossa. Red-coloured shallow, heavy soils resting on hard limestone or on hardened calcareous crust which is usually only a few inches thick, passing below into a much softer calcareous material. Some terra rossas are lime-free but others contain lime, which in certain areas may have been brought up by the plough. Some horizon differentiation is often seen in the deeper, less disturbed soils, the lower horizon being richer in clay and sesquioxides, of deeper red colour and often containing nodules of calcium carbonate. Osmond describes these soils as 'siallitic terra rossas' and distinguishes them from 'rotlehms' formed on igneous conglomerate cemented with calcium carbonate. The latter soils are often darker in colour than terra rossa and they shrink considerably when

dry. However, the darker colour is in certain cases due to deposition of silt through irrigation with flood waters. Although deep soils of this type are often found, in general they are shallow and may lie direct on calcareous crust formed on top of the conglomerate, so that the distinction in the field between terra rossa and earthy rotlehm is not always easy, the main criteria being shrinkage and stickiness, these characteristics being more marked in rotlehms than in terra rossas.

Brown earths (*braunerde*) formed on basic volcanic and plutonic rocks. They are generally lime-free, although veins of calcium carbonate often occur in the lower horizons, and of fine texture. Red soils (rotlehms?) also occur on such rocks but are less common. Possibly many brown earths are fairly juvenile soils formed after the original red soil had eroded away.

Raw soils. These may be grouped under two general types: carbonate raw soils formed on calcareous parent material, and silicate raw soils on volcanic and plutonic parent material. They contain a large proportion of unweathered rock fragments and are generally shallow, but in many areas the underlying rock is broken down mechanically to some depth. Where some horizon differentiation has taken place, e.g. some slight leaching of carbonates, they are probably better described as xerorendzinas. Many of these soils may well be the former C horizon of eroded, mature soils or even the soft calcareous material, once lying under the line crust of terra rossas, exposed by erosion and the breaking up of the crust by cultivation. In the same type of raw soils should probably be grouped large areas of man-made soils in the hills. In these areas erosion has largely removed the original soil and the underlying parent material, generally calcareous, has been broken up and made into bench-terraces mainly for planting vines.

Coastal sandy soils. These should probably be classed as raw carbonate soils. They consist of almost pure sand with a high carbonate content, mainly in the form of shells. They are of limited extent, but blown sand has affected the properties of soils over fairly large areas by admixture.

In general the cultivated soils of Cyprus are characterized by low organic-matter content, and alkaline reaction (the pH ranging from 7 in some non-calcareous terra rossas and brown earths to over 8 in calcareous soils), and they have been greatly modified by erosion or, to a lesser extent, by deposition.

The main crops are dry-land cereals under a cereal-fallow rotation, but in many places, especially where irrigation with spate waters in winter is practised and the soil is of sufficient depth, summer crops such as vetches (*Vicia ervilia*), water-melons, cotton, and others are grown in the fallow year. Vines, carobs, and olives are extensively grown without irrigation. Perennial irrigation from springs and wells has been practised since ancient times, but it has greatly expanded during the past few decades. The main irrigated crops are potatoes, vegetables, and citrus mainly in the coastal areas, and, to a lesser extent, cotton and vines. Deciduous fruit-trees under irrigation are confined to the southern range of hills, elaborate bench terraces being constructed to facilitate the

irrigation of cherry- and apple-trees. Although irrigation has resulted in a marked expansion of production in recent years, dry-land farming is still and is likely to continue to be the predominant form of agriculture in Cyprus.

Effect of Inorganic Fertilizers on the Yield of Potatoes

Potatoes are the main irrigated crop in Cyprus. Two crops are taken each year, the spring crop planted in February and lifted in June and the autumn crop planted in August and lifted in November. There are two main varieties, Arran Banner and Up-to-Date, giving approximately the same yield. More fertilizer experiments have been carried out with potatoes than with other crops, not only because of the importance of the crop, but also because of its high plant-nutrient requirements which make it valuable as an indicator crop for the assessment of soil fertility.

Experiments extending over 16 years have been carried out on all important agricultural soils in Cyprus. Care was taken to see that the experimental site had received no animal manure for some years prior to the experiment, but this was not always easy to determine. The usual design was a factorial one, $3 \times 3 \times 3$ or $3 \times 3 \times 2$ NPK, but other designs were adopted in some experiments. A general summary of the results obtained, for the response to nitrogen, phosphorus, and potassium, is given in Table 1.

TABLE 1. *Results of Fertilizer Experiments with Potatoes*

Nutrient	*Number of experiments*	*Number in which significant responses* ($P < 0.05$) *have been obtained*
Nitrogen . . .	22	20
Phosphorus . . .	20	14
Potassium . . .	23	nil

The fertilizers used were ammonium sulphate (20–21 per cent. N), superphosphate (16 per cent. P_2O_5), and sulphate or muriate of potash (48–50 per cent. K_2O). In none of these experiments was there any indication of an interaction of potassium with nitrogen or phosphorus, so the effect of potassium is ignored when discussing that of the other two nutrients.

Effect of Nitrogen and Phosphorus. The effects of nitrogen and phosphorus and their interaction in twelve factorial experiments is given in Table 2. The standard error in some of the experiments is high so that some fairly large yield-differences do not reach the required level of significance. The main cause of lack of precision was the difficulty of giving uniform irrigation to all plots, since in an attempt to carry out these experiments over as wide a range of soil conditions as possible,

TABLE 2. *Effect of Nitrogen and Phosphorus on the Yield of Potatoes (cwt. per acre)*

Locality and soil	*Yield without N and P*	*Unit nitrogen dressing (cwt. N. per acre)*	*Response to nitrogen*					
			In presence of phosphorus (double dressing)			*Without phosphorus*		
			Single dressing	*Increase to double dressing*	*Double dressing*	*Single dressing*	*Increase to double dressing*	*Double Dressing*
	1	2	3	4	5	6	7	8
1. Morphou. Calcareous alluvial clay loam	25·4	0·48	65·5‡	21·2†	86·7‡	57·8‡	22·9†	80·7‡
2. Akhna. Calcareous terra rossa clay	111·8	0·48	25·9†	0	25·9	6·1	0	6·1
3. Dhali. Calcareous alluvial loam	110·0	0·56	77·0‡	−32·0•	45·0†	12·0	−6·0	6·0
4. Xylophagou. Terra rossa clay	113·4	0·56	82·9‡	−20·7	62·2‡	52·5‡	−11·5	41·0†
5. Kokkinotrimithia. Calcareous terra rossa clay	179·1	0·56	61·2•	−28·8	32·2	−32·4	13·5	−18·9
6. Onishia. Gravelly rendzina clay loam	86·6[a]	0·48	12·5†	0	12·5†	−1·5	4·0	2·5
7. Avlona. Calcareous alluvial loam	90·9[a]	0·48	48·6•	−27·0	21·6	50·4•	−58·5•	−8·1
8. Argaki. Slightly calcareous terra rossa (rotlehm?) clay	115·3	0·48	59·3†	7·2	66·5†	29·4	32·4	61·8†
9. Galata. Brown earth clay loam derived from dolerite	109·3	0·48	101·3‡	21·1†	122·4‡	36·2†	45·0‡	81·2‡
10. Saitta. Sandy clay loam. Raw silicate soil on gabbro	33·7	0·48	82·5‡	−30·0•	52·5†	27·0	18·0	45·0†
11. Limnia. Highly calcareous raw carbonate soil clay loam	37·7	0·48	34·7‡	−10·4•	24·6†	0·7	−8·2	7·5
12. Avgorou. Terra rossa clay	86·6	0·48	22·7	11·7	34·4•	11·2	1·8	13·0
Mean	..	..	56·2	−7·3	48·9	20·8	4·4	25·2

a Mean of animal manure and no manure plots.

• Significant response at P = 0·05 level. † Significant response at P = 0·01 level. ‡ Significant response at P = 0·001 level.

the requirements of uniformity of the experimental field were in certain cases relaxed. Poor sprouting especially where the potatoes were planted in August was another cause. However, the results are consistent in showing a significant response to the single dressing of nitrogen in all experiments, and to that of phosphorus in eight out of the twelve. It is surprising, in view of the moderate dressings of nitrogen, that the response to the single dressing should have been so marked and that the response to the increase from the single to the double dressing was generally small or even negative. In six of the twelve experiments the increase to the double dressing was associated with a reduced yield, the reduction reaching significance in three. Only in two experiments was the effect of the increase to the double dressing positive and significant.

Although, in a series of experiments, apparently significant effects may arise by chance, the magnitude and frequency of the effect strongly indicates that the reduction in yield associated with the increase to the double dressing of nitrogen is a real effect. In an experiment not included in Table 2, where dressings up to 1·5 cwt. N per acre were

TABLE 2 (*cont.*). *Effect of Nitrogen and Phosphorus on the Yield of Potatoes* (*cwt. per acre*)

	Unit phosphorus dressing (*cwt.* P_2O_5 *per acre*)	*Response to phosphorus*						N/P *interaction* (*Enhancement of the response to* N *by* P)
		In presence of nitrogen (double dressing)			*Without nitrogen*			
		Single dressing	*Increase to double dressing*	*Double dressing*	*Single dressing*	*Increase to double dressing*	*Double dressing*	
	9	10	11	12	13	14	15	16
1	0·48	2·5	7·9	10·4	4·0	0·4	4·4	6·0
2	0·48	6·7	4·1	10·8*	−1·6	−7·4	−9·0	19·8*
3	0·56	32·0*	13·0	45·0†	6·0	0	6·0	39·0
4	0·56	59·8‡	−2·2	57·6‡	23·4*	13·0	36·4	21·2
5	0·56	38·7*	27·0	65·7*	6·3	8·1	14·4	51·3
6	0·37	19·0†	3·3	22·3‡	9·5*	3·0	12·5†	9·8
7	0·37	90·1†	−29·8	60·3*	0	30·5	30·5	29·8
8	0·37	−7·2	26·1*	18·9*	27·7*	−13·4	14·3	4·6
9	0·37	34·3†	7·7*	42·0‡	1·8	−0·9	0·9	41·1†
10	0·37	45·0†	−30·7*	14·3	6·7	0	6·7	7·6
11	0·37	32·1‡	13·3†	45·4‡	2·1	11·2*	13·4†	32·0‡
12	0·37	21·9	−0·4	21·5	−4·6	4·8	0·2	21·3
	..	31·3	3·3	34·6	6·8	4·1	10·9	..

* Significant response at P = 0·05 level. † Significant response at P = 0·01 level. ‡ Significant response at P = 0·001 level.

applied, the yields were 0·5 N, 105 cwt.; 1·0 N, 104 cwt.; 1·5 N, 76 cwt.; the reduction with the increase from the double to the treble dressing being highly significant. It was noted that in certain experiments a large proportion of tubers in the plots receiving the higher levels of nitrogen had rotted in the field. Since only sound tubers were weighed, in some cases the negative response to high levels of nitrogen was possibly due to its adverse effect on quality rather than on total production. It is difficult to explain, however, why the adverse effect of high dressings of nitrogen should have been more marked in the presence than in the absence of phosphorus.

As with nitrogen, the effect of the increase from the single to the double dressing of phosphorus was on the whole insignificant. In eight out of the twelve experiments the difference was positive but in only three did it reach the P = 0·05 level of significance. In two experiments the yield was markedly depressed, the difference reaching significance in one.

The average effect of nitrogen and phosphorus in Table 2 may be

compared with that obtained in other experiments as shown below, the dressings being approximately the same in the two groups:

	cwt. per acre
Mean response to single dressing of N	33·2
,, ,, increase from single to double dressing of N	5·0
,, ,, single dressing of NP	27·8

In some of these experiments with nitrogen there was a small basal dressing of nitrogen, which explains the lower mean response to the single dressing in this group as compared with Table 2. The mean effect of phosphorus agrees well with that in Table 2.

Column 16 of Table 2 gives the enhancement of the effect of the double dressing of nitrogen by the presence of the double dressing of phosphorus. Following the example of Russell and Garner [4] the actual enhancement is given and not the NP interaction as defined by Yates [5]; to obtain that value for the interaction the figures in column 16 should be divided by 2. This enhancement was invariably positive, but it reached significance in only three experiments. Much more striking differences in the response to nitrogen with and without phosphorus are obtained if the effect of only the single dressing of nitrogen is considered, as may be seen by subtracting the figures in column 6 from those in column 3. There can be little doubt that in most soils there was a real positive NP interaction and the failure of this interaction to reach significance in the majority of these experiments is a reflection of the fact that interactions in general are determined with a lower precision than main effects.

On the whole, dressings not exceeding 0·5 cwt. N and P_2O_5 per acre were adequate and higher dressings were rarely effective. They correspond to about 2·5 cwt. ammonium sulphate and 3 cwt. superphosphate per acre. The dressings actually applied by potato growers in Cyprus may be three or four times as high. Apart from the waste thus caused, there is the danger that excessive dressings of N may depress the yield.

There is little evidence of any differences among soil types as regards the effect of phosphorus, the variations observed among the various experiments in the response to this nutrient being probably due to past treatment. In actual fact, marked differences have been noted in this respect between experiments carried out in the same locality, on the same soil type and in the same season.

The effect of potassium. As already indicated in Table 1, potassium consistently failed to raise the yield. In certain experiments it actually caused a reduction. Table 3 gives details of the results obtained with potassium in all twenty-three fertilizer experiments.

The failure of potassium to raise the yields of crops seems to be fairly general in semi-arid regions. Thorne and Peterson [6] state: 'Most surveys of potassium in the larger irrigated areas of western United States indicate adequate quantities are present for current crop needs.' Even in certain humid or subhumid regions potassium reserves may be adequate. J. T. Ramsay [7] gives a summary of potato fertilizer experiments carried out over a number of years in Australia, from which it appears

TABLE 3. *Effect of Potassium on the Yield of Potatoes (cwt. of tubers per acre)*

Experiment	*Mean yield without potassium*	K *in single dressing (cwt.* K_2O*/acre)*	*Response to*		
			Single dressing	*Increase to double dressing*	*Double dressing*
1	78·0	0·48	1·8	−7·3*	−5·5
2	117·7	0·48	2·1	0	2·1
3	147·0	0·56	−2·0	−14·6	−21·8
4	190·7	0·56	−17·0*	−6·5	−23·5†
5	196·6	0·56	19·1	−36·3	−17·2
6	100·8	0·37	−3·7	3·2	0·5
7	128·5	0·56	4·0	..	..
8	155·7	0·56	1·5	..	..
9	171·7	0·56	1·5	..	..
10	69·2	0·56	3·7	..	..
11	56·4	0·48	−2·8	−0·4	−2·4
12	105·7	0·48	3·1	−0·7	3·6
13	179·5	1·10	−16·2*	..	..
14	184·8	0·60	6·0	..	..
15	126·3	0·90	8·2	..	..
16	153·1	0·90	5·4	..	..
17	134·7	0·90	3·1	..	..
18	96·0	0·56	−3·4	..	..
19	180·0	0·75	6·1	..	..
20	115·0	0·75	4·5	..	..
21	237·0	0·75	6·7	..	..
22	183·0	0·56	3·4	..	..
23	127·8	0·48	0·3	..	..

* Significant response at P = 0·05 level. † Significant response at P = 0·01 level.

that out of thirteen districts of Victoria only in one was the need for potassium demonstrated, although the requirements for phosphorus and in the second place nitrogen, were high. The average annual rainfall of these districts ranged from 35 to 60 inches.

It should be noted, however, that both the United States and Australia are countries only recently opened for agriculture, whereas in Cyprus and other countries of the Middle East, where, too, the need for potassium is small, agriculture is as old as history. On the other hand, most of the land in the countries of the Middle East has until recently been under the wheat-fallow rotation, receiving neither nitrogen nor phosphorus fertilizers nor irrigation. The removal of potassium under this system must be very low, not exceeding 10–15 lb. per crop per acre.

The rapid expansion of irrigation and of the use of nitrogen and phosphorus fertilizers, with the resultant marked rise in productivity, has created conditions that may bring about the depletion of the potassium reserves of the irrigated soils of Cyprus. There are, however, certain factors that counteract this process. In the first place most irrigated soils receive occasional dressings of animal manure, although, as the area under irrigation expands, such dressings will become less and less frequent.

Most Cyprus waters in the lowlands contain useful amounts of

potassium, figures up to 20 parts K per million being not infrequent. Assuming 30 inches of irrigation water, containing 10 parts K per million, to be applied annually, this would correspond to a dressing of 0·60 cwt. potassium (equivalent to 0·73 cwt. K_2O) per acre. However, many irrigation waters, especially those obtained from the igneous formations, contain less than one part potassium per million.

On the basis of limited analytical data, the soils of Cyprus in general appear to contain considerable amounts of total potassium, ranging from 0·8 to 1·5 per cent. The basic and, especially, the ultrabasic plutonic rocks are much poorer, their potassium content being as low as 0·3 per cent. The total potassium content of the clay fraction (0·002 mm.), however, is usually not higher than 0·25 per cent. This and their high base-exchange capacity shows the clays of the Cyprus soils to be predominantly montmorillonitic, although illitic clays probably occur. The bulk of potassium must therefore occur in the silt and sand fractions, presumably as primary minerals. Potassium in minerals such as micas and feldspars is known to be moderately available to plants. Exchangeable potassium ranges from 0·2 m.e. per 100 gm. soil in soils derived from basic plutonic rocks to 3 m.e. in terra rossas, the corresponding percentages of the total basic exchange capacity ranging from less than 1 to over 10 per cent. In general the soils of Cyprus appear to be well supplied with potassium with the exception of those derived from basic plutonic rocks.

On the basis of these experiments, farmers in Cyprus are being advised not to apply potassium fertilizers. In view of the cost and the risk that high amounts of potassium may reduce the yield, it is not considered a sound practice to apply potassium fertilizer as a safeguard against possible deficiency. The position is being watched, however, and long-term experiments are being planned which should render possible the detection of any possible deficiency of potassium that may develop under intensive cropping. It may be expected that soils of the basic igneous formations will be the first to be depleted of their potassium reserves.

Effect of Animal Manure on the Yield of Potatoes

The effect of animal manure was studied in only two experiments. It is necessary to point out that animal manure in Cyprus has little relation to the farm-yard manure of northern Europe. Its moisture content is only 10–20 per cent. and its nitrogen content on a dry-matter basis rarely exceeds 1 per cent., a fact which points to large losses of nitrogen on storage.

The results of the first experiment on calcareous, alluvial clay loam with goat manure, are summarized in Table 4.

In the second experiment (No. 6 of Table 2) cattle manure was used. The results are summarized in Table 5.

Thus while goat manure had no effect, cattle manure had a marked effect exceeding that due to inorganic fertilizers alone. Although goat and sheep manure are generally considered superior to cattle manure in Cyprus, in these experiments the quality of goat manure was below average, containing only 0·8 per cent. N, and that of cattle manure above

TABLE 4. *Effect of Goat Manure on the Yield of Potatoes (Calcareous alluvial clay, Avlona)*

Dressing[1]	*Yield*[2] *(cwt. per acre)*
No fertilizer . .	147 ± 14·7
Goat manure . .	154 ± 14·7
NP	207 ± 9·2
NP and goat manure .	214 ± 9·2

[1] Goat manure, 225 cwt.; N, 1·15 cwt. nitrogen as ammonium sulphate; P, 1·15 cwt. P_2O_5 as superphosphate; all per acre.
[2] Mean of potassium and no-potassium plots.

TABLE 5. *Effect of Cattle Manure on the Yield of Potatoes (Gravelly Rendzina clay loam, Onishia)*

Dressing[1]	*Yield (cwt. per acre)*
No fertilizer . .	70·5
M_1	85·0
M_2	103·5
N_2P_2	99·0
$N_2P_2M_1$ . . .	115·5
$N_2P_2M_2$ . . .	118·5

Standard error (40 DF): ±7·3.

[1] M_1, 75 cwt. cattle manure; M_2, 150 cwt. cattle manure; N_2P_2, 0·46 cwt. N, 0·74 cwt. P_2O_5 as ammonium sulphate and superphosphate respectively; all per acre.

average containing 1·10 per cent. N, on a dry-matter basis. It is not possible in this paper to give full details of the experiment with cattle manure, but it is interesting to note that the interaction of manure with superphosphate was negative and nearly significant while that of manure with ammonium sulphate was very small. This agrees with the statement of Crowther and Yates [8] that the effect of manure is less in the presence of phosphorus fertilizers, but is not influenced by addition of nitrogen fertilizers.

Much more work is needed on the effect of animal manure on the yield of potatoes and other crops. It should be noted that manure in Cyprus is not normally produced on the farm; most of it is obtained from landless flock owners at prices which are probably uneconomic. Unless a radical change in the pattern of agriculture takes place farmers should rely mainly of inorganic fertilizers.

The Effect of Time of Application and of Type of Nitrogenous Fertilizers on the Yield of Potatoes

The usual time of application of the nitrogen as well as the phosphorus fertilizer is at planting. Nine experiments have been carried out to determine the effect of time of application. In only one experiment was

late application of nitrogen significantly more effective than application at planting. The mean results obtained in these experiments are given in Table 6.

TABLE 6. *Effect of Time of Application of Nitrogen Fertilizer on the Yield of Potatoes (mean of nine experiments). Yield of Tubers (cwt. per acre).*

Nitrogen dressing (cwt. per acre)	*Fertilizer applied at*	
	planting	*one-half at planting, one-half later*
0·48	170	167
0·96	175	180

In six of these experiments only ammonium sulphate was applied. In one, ammonium sulphate was applied at planting and sodium nitrate a month later. In the remaining two, ammonium sulphate was compared with Nitrochalk and sodium nitrate, only one kind of fertilizer being applied to any one plot. In one of these two the split application gave significantly better results than when all was applied at planting, the effect being shown by all three fertilizers. Thus time of application had a significant effect in only one out of nine experiments.

In three experiments the effect of applying the nitrogen fertilizer in three doses was tried: at planting, one month, and two months later, but the results hardly differed from those obtained with the other two times of application.

It is not surprising that time of application in general had little effect on the yield. After planting in February, rainfall during the succeeding months rarely exceeds 2–3 inches and very little leaching of nitrates may be expected. Similarly with the autumn crop, there is hardly any rainfall in August and September and the crop is given only one or two irrigations during the first month after planting so that loss by leaching must be very low.

No differences in the effect of the fertilizers have been observed in the two experiments designed to compare ammonium sulphate, sodium nitrate, and Nitrochalk. The mean yields are given in Table 7.

TABLE 7. *Effect of Type of Nitrogen Fertilizer on the Yield of Potatoes (mean of two experiments; cwt. per acre)*

Nitrogen dressing (cwt./acre)	*Ammonium sulphate*	*Sodium nitrate*	*Nitrochalk*
0·48	177	165	165
0·90	171	169	171

These nine experiments suffer from the fact that there were no treatments without nitrogen. Since there was no response to the increase to the second level of nitrogen, it has to be assumed that the yields with nitrogen were significantly higher than they would have been without it.

Such an assumption is, however, highly probable in view of the consistent effect of nitrogen in practically all experiments in which it has been tried and also of the fact that most of the nine experiments were carried out in the same fields and at the same time as other experiments in which a marked response to nitrogen was obtained.

The response of potatoes to various types of phosphorus fertilizer will be given in a subsequent paper.

Onions

Only one experiment was carried out. The soil was a shallow calcareous terra rossa clay. The fertilizers were ammonium sulphate and superphosphate applied at three levels each in a factorial design. As there was no indication of interaction, only the mean yields at the different levels of each fertilizer are given in Table 8.

TABLE. 8. *Effect of Ammonium Sulphate and Superphosphate on the Yield of Onions (cwt. bulbs per acre)*

Nitrogen dressing (cwt./acre)	*Mean yield*	*Phosphorus dressing (cwt. P_2O_5/acre)*	*Mean yield*
Nil . . .	146·3	Nil	161·5
0·45 . . .	175·1	0·36	167·0
0·90 . . .	175·1	0·72	169·0
Standard error (16 DF): .	±8·6	. .	±8·6

The effect of superphosphate was not significant but there was a significant response to the single dressing of nitrogen. The increase was entirely due to the larger size of the bulbs, their number per acre being determined by spacing, which in this experiment was the same for all treatments.

Cotton

Three experiments were carried out with cotton under irrigation. The variety was Coker 100, an American upland type extensively grown in Cyprus. In all three experiments ammonium sulphate and superphosphate were used in a 3×3 factorial design. The fertilizer was applied with the seed in April. The soil types were:

Expt. 1. Deep calcareous alluvial clay.
Expt. 2. Deep calcareous reddish brown clay on old alluvium.
Expt. 3. Deep calcareous alluvial clay loam.

The results are given in Table 9.

The NP interaction was very small and significant and is omitted. Nitrogen and phosphorus each had a significant effect in the first two experiments while no yield difference reached significance in the third. While the increase to the double dressing of nitrogen had no effect in any experiment, the effect of that increase in the dressing of phosphorus was significant in experiment 1. These results agree with those obtained in 1936–8 by Frangopoulos [9], who also tried potassium without result.

TABLE 9. *Effect of Ammonium Sulphate and Superphosphate on the Yield of Cotton (cwt. of seed cotton per acre)*

	Expt. 1	*Expt. 2*	*Expt. 3*
Single dressing of N (cwt./acre)	0·30	0·45	0·45
Mean yield:			
without N	4·74	4·62	8·17
with single dressing of N	6·60	6·89	9·52
with double dressing of N	6·16	6·68	8·40
Single dressing of P (cwt. P_2O_5 per acre)	0·22	0·36	0·36
Mean yield:			
without P	4·95	5·43	8·77
with single dressing of P	4·87	6·20	8·40
with double dressing of P	7·66	6·45	9·00
standard error (8 DF)	±0·63	±0·23	±0·70

In general the fertilizer requirements of cotton appear to be similar to those of potatoes.

Determinations of lint length were made in experiment 2. This varied from 25·2 to 32·4 mm., with an average of 28·5. Neither fertilizer alone had any effect, but together they appeared to raise the length of lint, the effect being nearly significant at the $P = 0{\cdot}05$ level.

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THE INFLUENCE OF PLANTING DATE ON TOBACCO GROWTH AND ON THE INCIDENCE OF CERCOSPORA LEAFSPOT DISEASE IN SOUTHERN RHODESIA[1]

R. C. STEPHEN

(*Tobacco Research Board of Rhodesia and Nyasaland*)

Summary

From the results of experiments carried out in two seasons (1952/3 and 1953/4) it is concluded that date of transplanting from seed-beds to field was one of the most important factors in relation to tobacco production and the incidence of Cercospora leafspot disease.

The highest yields of best-quality leaf were obtained from early plantings, before approximately 20 November; delay in planting date thereafter resulted in large progressive yield reductions associated with correspondingly poorer-quality leaf.

The incidence of Cercospora leafspot disease was least on early-planted tobacco and as planting date became later there was first a progressive increase in spot intensity, reaching a maximum and thereafter decreasing slightly in late-planted crops. There was no conclusive evidence of a direct relationship between this disease-incidence pattern and either temperature, rainfall, or the number of rain days.

In the past, the transplanting of tobacco seedlings from the seed-bed to the field commenced towards the end of November once the rainy season had set in, and continued in December when the majority of the tobacco crop was planted. Plantings were 'staggered' throughout this period for management reasons, of which two were shortage of barn accommodation and labour requirements at critical periods.

Experiments were carried out to determine the influence of transplanting date on tobacco growth, concerning which there appeared to be few experimental data. At the same time the influence of planting date on the incidence of Cercospora leafspot disease (*Cercospora nicotianae* (Ell. & Ev.)) was examined, since this disease was very prevalent in the colony and according to Hopkins [1, 2, 3] was responsible for a greater annual loss to the tobacco industry than any other disease.

Review of Literature

Brown [4] observed that, under Southern Rhodesian conditions, the highest returns were normally secured from transplantings made during the latter half of November and up to the end of December.

O'Callaghan [5] studied the relation of planting date and tobacco growth in a single trial which included transplantings made at approximately fortnightly intervals from 9 November to 26 January. The yield of the 26 January planting was less than half that of the others, in which

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a maximum yield of 1,338 lb./acre was obtained from tobacco planted on 22 November, followed by a gradual reduction to 1,070 lb./acre from 6 January plantings.

Seedlings, free from frog-eye infection, were transplanted on 24 November in Rhodesia by Norval [6], who observed that the first indications of the disease occurred in early January. By the end of January there were many lesions visible on the lower leaves.

Reports on the relation of climatic factors to the incidence of Cercospora leafspot disease of tobacco were made by Hopkins [2, 3] and Henderson (cited by Hill [7]), who observed that the disease was more severe during periods of continued rain. Hill [7], in Australia, recorded that during the seasons 1931–3, when epidemics occurred, the disease was worst when the mean weekly temperature was between 25·5° C. (77·9° F.) and 27° C. (80·6° F.); above and below these temperatures the disease was checked almost altogether. Hill further reported that there was no direct relationship between disease outbreaks and either the monthly rainfall or the number of rain days per month, but concluded that the optimum conditions for disease-spread were a combination of high temperature and wet weather.

Materials and Methods

Cultural details. Transplanting of disease-free seedlings was carried out using hand transplanters calibrated to deliver approximately one-fifth of a pint of water simultaneously with each seedling. Experimental plots were 1/100 acre in size and consisted of two rows of thirty-one plants spaced 3 ft. 6 in. between rows and 2 ft. within the row. End plants and guard rows bordering the experimental plots were discarded to eliminate border effects. All the experiments were of replicated randomized-block or factorial design.

Yield and quality assessment. The yield per acre, expressed in lb., was adjusted on a stand basis since the stand in all plots was well over 90 per cent.

Leaf quality was assessed as a grade index which represents the relative value of leaf produced. An index scale varying from zero for leaf of no commercial value to 100 for the best leaf is in current use by the Tobacco Research Board of Rhodesia and Nyasaland. By applying these relative values to the recorded weight of leaf in the appropriate grade, the grade index per plot was calculated as shown by the formula:

$$\text{Grade index} = \frac{\text{Sum of (Wt. of leaf in each grade)} \times \text{(grade value on scale)}}{\text{Wt. of graded leaf per plot}}.$$

Disease incidence assessment. Infection by *C. nicotianae* in the field may take two forms. In the first there is visible evidence of infection by the production of spots on leaves in the field, this phase being commonly known as frog-eye. In the second, however, it seems possible that the fungus can grow within the tissues, constituting a source of latent infection which passes unnoticed because of the absence of visible lesions; brown spots known as barn spots develop during curing from

this incipient field infection if low temperatures and humidities are employed during the colouring period.

Accordingly the assessment of treatment effects was made on the cured leaf, which was sorted into four categories, clean, lightly, moderately, and heavily spotted leaf. The weight of leaf in each category was recorded and the final disease incidence was calculated as an Infection Index using the McKinney Grouping System [8, 9, 10]. The data per plot were thus reduced to a single weighted percentage by the formula:

$$\text{Infection Index} = \frac{\text{(Wt. of lightly-spotted grade)} + \text{(Wt. of medium-spotted grade} \times 2) + \text{(Wt. of heavily-spotted grade} \times 3)}{\text{(Total wt. of leaf} \times 3)} \times 100.$$

Experimental Section

Experiments were carried out over two seasons, 1952/3 and 1953/4, and for convenience the relation of planting date to the yield and quality of tobacco and to the disease incidence are dealt with separately.

The date-of-planting factor was arbitrarily divided into three categories, namely early, medium, and late. 'Early' planting, as described herein, included the period up to 20 November; plantings from 20 November up to mid-December were considered as 'medium', and thereafter all plantings were termed 'late'. According to this classification the time of planting advocated by Brown [4] and adopted to a very large extent for experimental work in the past at Trelawney [11] was medium and late.

Relation of planting date to the yield and quality of tobacco

Six dates of planting, at approximately fortnightly intervals, were tested in the two seasons, covering almost the same period, namely 31 October to 14 January. Apart from seasonal variation in climatic conditions the main difference between the experiments in the two seasons was in the colouring procedure adopted during curing. In the 1952/3 experiments low colouring temperatures and humidities were used, conditions which do not restrict barn-spot development. In the 1953/4 experiment the leaf was yellowed at temperatures of 100°–102° F. with 100 per cent. humidity attained by using steam; under these conditions barn-spot development is restricted and very few barn spots appear [12]. The results of the main experiment in 1952/3, and the experiment in 1953/4 are shown in Table 1.

These results demonstrate that the date of planting was one of the more important factors affecting the yield and quality of flue-cured tobacco in Southern Rhodesia.

Delay in planting caused a progressive reduction in the yield obtained, the general pattern being the same over the two seasons. In the 1952/3 season the late-planted tobacco yield was only half that obtained from the early plantings and the yields of the medium plantings occupied an

TABLE 1. *Yield and Grade Index for different Planting Dates*

Planting date 1952/3	*Yield lb./acre*	*Grade index*	*Planting date 1953/4*	*Yield lb./acre*	*Grade index*
31 Oct. . . .	1,375	48·3	8 Nov.	1,290	51·7
14 Nov. . .	1,302	52·0	19 Nov.	1,278	45·3
28 Nov. . .	1,102	29·8	3 Dec.	1,068	46·0
12 Dec. . .	811	27·4	17 Dec.	471	32·4
26 Dec. . .	599	27·4	31 Dec.	196	9·3
12 Jan. . .	608	21·8	14 Jan.	147	0·0
Least significant differences:					
P = 0·05 .	86	2·7	..	77	1·8
P = 0·01 .	119	3·8	..	106	2·5
P = 0·001 .	165	5·2	..	144	3·4
Mean . . .	966	34·4	..	742	30·8

intermediate position. In the following season the yields obtained from late-planted crops were only from 10 to 15 per cent. of those obtained from early plantings.

Whilst leaf quality was highest in the early-planted crops, in both experiments the grade indexes recorded for later plantings varied somewhat in each experiment though there was a general reduction with delay in date of planting. In the 1952/3 experiment there was a drop of approximately 43 per cent. in the medium-planted index with a further drop of about 10 per cent. in the late-planted index. In the following season, although there was not the same sharp reduction in grade index with the medium plantings, this occurred with the late-planted crops.

These results were corroborated by other less comprehensive date-of-planting experiments [13] carried out in the 1952/3 season. In the first, plantings were carried out on 11 November, 1 and 22 December, the yield and grade indexes of which were 1,234, 1,306, and 739 lb./acre and 42·2, 37·8, and 32·8 respectively. Two dates of planting were compared in another experiment, namely 14 November and 15 December, for which the corresponding yields and grade indexes were 1,399 and 973 lb./acre and 45·3 and 35·1 respectively.

It was concluded, therefore, that tobacco should be planted before approximately 20 November for the greatest financial returns from the high yields of first-grade leaf. The late plantings on 31 December and 14 January in the 1953/4 experiment were commercially valueless and this conclusion illustrated that severe financial loss could be incurred by commercial growers with late-planted crops in certain seasons.

Relation of planting date to the incidence of Cercospora leafspot disease of tobacco

The same two experiments, for which yield and quality data are shown in Table 1, were examined to determine the incidence of Cercospora

leafspot disease at each date of planting. In addition the other two experiments mentioned above [13] were examined during the 1952/3 season. The final amounts of leafspot on the cured leaf from each experiment are given in Table 2.

TABLE 2. *Infection Index (see p. 293) for Different Planting Dates*

*Planting date 1952/3**		*Experiment*			*Planting date 1953/4†*	*Experiment*
		1	*2*	*3*		*4*
Early	31 Oct.	21·6	..	..	..	..
	11 Nov.	..	32·4	..	8 Nov.	11·6
	14 Nov.	55·6	..	50·2	19 Nov.	24·2
Medium	28 Nov.	83·7	..	..	..	..
	1 Dec.	..	75·7	..	3 Dec.	18·4
	12 Dec.	78·6	..	..	..	..
	15 Dec.	..	..	69·4	17 Dec.	32·2
Late	22 Dec.	..	44·3	..	..	..
	26 Dec.	70·5	..	..	31 Dec.	13·7
	12 Jan.	55·7	..	..	..	..
Least significant differences:						
$P = 0{\cdot}05$		8·2	3·8	6·2	..	3·4
$P = 0{\cdot}01$		11·3	5·1	8·7	..	4·7
$P = 0{\cdot}001$		15·7	7·0	12·1	..	6·5
Mean		60·9	50·8	59·8	..	22·0

* Barn-spot development not restricted in 1952/3 experiments.

† Barn-spot development restricted in 1953/4 experiments by use of high temperatures and humidity during the yellowing phase of curing.

These results show that the final incidence of frog-eye and barn spot on the cured leaf in the 1952/3 experiments was lowest on the early As the planting date became later there was first a progressive increase in the amount of spotting, reaching a maximum during the medium plantings with an increase of approximately 50–60 per cent. in spot intensity. Thereafter, in the late-planted crops, the disease incidence decreased though the amount did not fall to the low levels recorded for the earliest planting.

In the 1953/4 experiment the incidence of frog-eye increased progressively with delay in planting with the exception of the third planting, the maximum being attained in the medium planting carried out on 17 December. Thereafter the incidence decreased and the results agreed in general with those obtained in the previous season.

The general level of infection was considerably lower in the 1953/4 experiment than in the previous season, the reduction being attributable in part to the control of barn-spot development effected by the use of high colouring temperatures and humidities during curing.

From these results it was concluded that early planting was a worthwhile measure for the control of the disease. Medium plantings were apparently liable to severe infection, decreasing only slightly in late plantings.

Relation of climatic conditions to the disease incidence at various dates of transplanting tobacco to the field

Temperature and rainfall records were examined to determine whether there was any relation between these factors and the variation in degree of infection which occurred on tobacco planted at different times. The 1952/3 season was selected since there was a much wider variation in the final disease incidence on cured leaf in that experiment, than in the 1953/4 experiment.

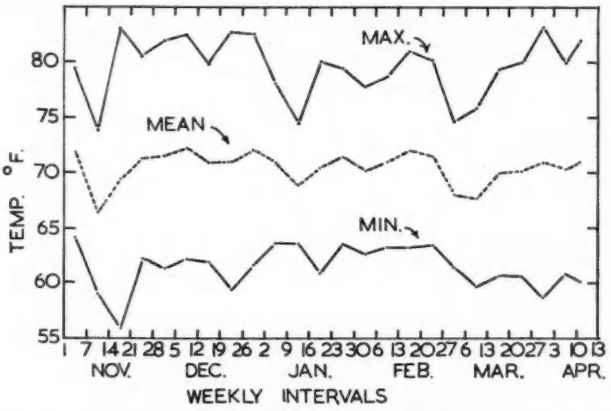

FIG. 1. Maximum, minimum, and mean weekly temperatures for week commencing 1 November 1952 to 13 April 1953.

The temperature was recorded within a Stevenson screen and rainfall in a standard rain gauge close to the date-of-planting experiment.

The relevant data are illustrated in Fig. 1. and Fig. 2.

The mean weekly temperatures were extremely uniform throughout the whole period and with one exception were within the range of 68°–72° F. The disease was first observed in late December on the earliest plantings and increased in intensity thereafter on this and later plantings. Since the temperature was very little different before, during, or after the first signs of infection it seemed that there was no correlation between the temperature and incidence of disease.

The total amounts of rainfall recorded for the period of growth in the field were very little different for each date of planting; 19·43, 15·25, and 15·48 inches of rain were recorded for the first three plantings respectively, whilst the infection index on cured leaf was 22, 56, and 84 per cent. for the same dates. The last three plantings had more rain, on the average, than the earlier three but the subsequent infection index dropped from 79 to 71 to 56 per cent.

The amounts of rain which fell from transplanting time to the first reaping showed little difference between the first three plantings or between the last three plantings, though the level of rainfall for the latter was slightly higher. The quantity of rain recorded from topping time

to final reaping decreased with delay in planting. It was apparent, therefore, that the final incidence of the disease was not obviously related to rainfall. Furthermore, it seemed that the number of days on which rain fell were not correlated with the disease incidence.

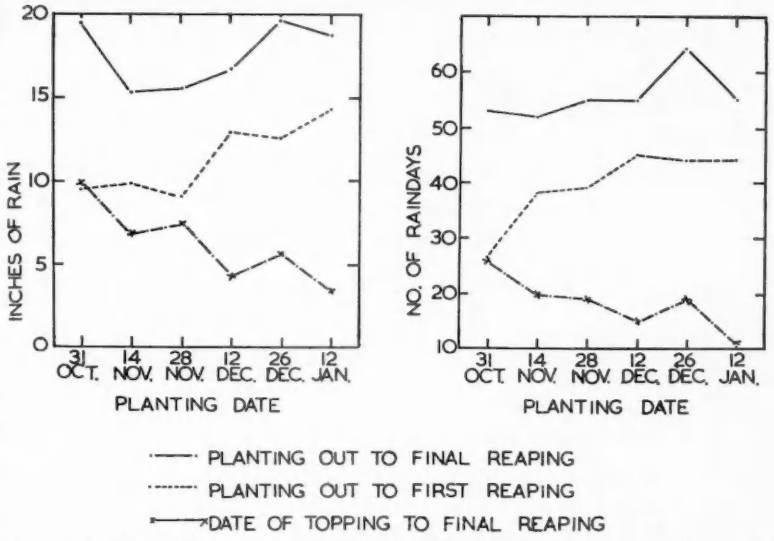

FIG. 2. Rainfall and number of rain days for different periods in each of six planting dates during 1952/3.

Discussion

The experiments reported herein demonstrated that transplanting tobacco seedlings to the field could be undertaken during the first week of November. The success of this procedure was attributed to the fact that water was distributed about the region of the roots at the time of setting, provided that the seedlings had been properly hardened off in the seed-beds to withstand the shock of transplanting.

Stinson [14] reported that there was sufficient soil moisture for October planting at Salisbury[1] in three, and at Trelawney[1] in four, out of the ten seasons 1943–53, and at Karoi[1] in two out of the three seasons 1950–3; he further observed that moisture was adequate for November planting in each year from 1943 to 1953 at the three stations named, except in one season at Salisbury. From records at Trelawney [11] it was noted, however, that the majority of experiments were not planted until December and the earliest recorded planting was 19 November, dates which agreed with Brown's [4] recommendations.

Time of planting was shown to be one of the most important factors affecting the yield and quality of tobacco. The highest yields of between

[1] Trelawney is situated about 50 miles to the north-west of Salisbury with Karoi a further 100 miles beyond Trelawney in the same direction.

1,200 and 1,400 lb./acre were obtained from tobacco planted early, before mid-November; thereafter there was a progressive reduction. Leaf quality followed the same pattern although the very marked drop in the grade index in the medium plantings in the 1952/3 crop, as compared with the early plantings, may have been due in part to the very high incidence of Cercospora leafspot disease on leaf from those plantings.

It would appear that the highest financial returns were obtained from the earliest plantings and these were considerably reduced with delay in planting thereafter. Late planting in the 1953/4 season was not an economical proposition and financial loss would have been incurred by growers who relied on such crops. These results are not in agreement with those of Brown [4], who suggested that the highest returns were usually secured when the crop was transplanted during the latter half of November and up to the end of December. It was accepted as general practice by commercial growers to put out the main bulk of their crops during this period and the results of this practice are reflected in the low average yields for the colony. Stonhill [15] records average yields of 663, 649, 683, 533, and 500 lb./acre for the flue-cured tobacco crops in Southern Rhodesia during the five years from 1948 to 1952 respectively. The average yields from crops transplanted during the period 20 November to 31 December in the two experiments carried out were 837 and 578 lb./acre, which are in line with Stonhill's data.

It is not possible to attribute the high yields of first-grade leaf obtained by early planting and the progressive reductions in yield and quality thereafter, to any one reason. Hunter [16] suggested that the effects were the additive result of many factors probably related to weather conditions, and he proposed the following possibilities:

(*a*) the beneficial effects of periods of low rainfall early in growth as recorded by Stinson [4];
(*b*) that the release of available nitrogen from organic matter occurs in November–December, which should benefit only early-planted tobacco; and
(*c*) that early-planted tobacco has an adequate amount of nutrients in the soil during the growing period, while towards the end there is likely to be a deficiency of nitrogen, induced by extensive leaching during the main rains in January. This set of conditions is regarded as favourable for high yields and quality.

The experiments further showed that the final incidence of Cercospora leafspot disease on cured leaf was lowest on the early-planted tobacco. There was a progressive increase in spot intensity which reached a maximum in the medium plantings carried out on 28 November and 12 December, followed by a gradual decrease thereafter. Since there appeared to be no obvious correlation between this change and the temperature, rainfall, or the number of rain days, the pattern appeared to be determined by factors other than climatic ones, though these latter were probably important in other ways.

Uniform seedlings, free from frog-eye infection, were used and it

seems unlikely that seedling variations were responsible for the differences recorded. The experimental plots were situated in an isolated land with at least half a mile separating them from the nearest tobacco. In view of Park's conclusions, cited by McLean [17], that viable spores of *C. nicotianae* were not transmitted as much as 100 yards by air currents, it appeared that other areas carrying tobacco could not have acted as sources of infection. There appears to be no record of *C. nicotianae* being able to survive in the soil and therefore the inoculum is not likely to have arisen from this source.

The only other possible source of infection was the veld vegetation surrounding the experimental site. Under Rhodesian conditions tobacco is the only known host of *C. nicotianae*, though Hopkins [18] listed twenty other species of Cercospora and three Mycosphaerella species which are found on wild, cultivated, and crop plants in that country. In America, however, Johnson and Valleau [19] demonstrated that the organism causing typical frog-eye on tobacco was able to exist on sixteen different plant species unrelated to tobacco. It is possible, therefore, that hosts of *C. nicotianae*, other than tobacco, may exist in the veld vegetation. Consequently it seems possible that the veld vegetation may provide the main source of spore inoculum to establish primary infection in the tobacco crop.

The fungus should be able to survive the rainless period from May to September in its sclerotia-like stage within the leaf tissues of alternative hosts, as is possible in tobacco leaf [7, 20]. Once the rainy season has set in, the veld vegetation starts to grow and infection and development of the fungus within the tissues of the new veld growth can then take place from conidia produced on previously infected leaves.

Possibly a certain period may elapse before conditions are favourable for conidial production in any quantity. The absence of spores during this period, therefore, would account for the non-appearance of the disease on early-planted tobacco up to mid-December. Following this period an increasing number of conidia may be available to infect the crop which would partly account for the marked increase in infection in the medium plantings as compared with the earlier ones. From the latter half of February onwards, the rainfall intensity and frequency decrease. There would be a tendency for a general decline in the vegetation and conidial production by the organism which would probably cease as the sclerotia-like stage was developed. Thus late plantings of tobacco would be subjected to fewer spores with consequently a lesser amount of disease.

It would thus appear possible that the pattern of low, high, and medium infection of tobacco leaf by *C. nicotianae* may be primarily controlled by the amount of spore inoculum available. If the hypothesis that the veld vegetation is the main source of spore inoculum is correct then the largest numbers of conidia would be produced in mid-December and January. Seedlings transplanted about the beginning of December would be exposed to the greatest numbers of conidia over the period of the main growth of the crop and therefore the disease incidence would be severe. This observation partially confirmed Hopkins's [2, 3]

and Henderson's suggestion (cited by Hill [7]) that the disease was generally more severe during periods of continued rain although the considerations discussed above suggest that the primary factor is the number of spores available and this coincides with the wettest period. The latter is, however, important from the point of view of providing suitable conditions for infection.

The relationship of disease incidence with temperature found by Hill [7] was not confirmed. There was no direct relationship between disease intensity and the rainfall or the number of rain days corresponding to the plantings made at different times and this observation agreed with Hill's [7] work.

The practice of early planting is, therefore, not only desirable from the point of view of its beneficial effects on tobacco growth, but is also a worth-while measure for reducing the incidence of Cercospora leafspot disease.

In investigations of this type it is desirable, especially with regard to the disease aspect, that experiments should be carried out over a number of seasons to enable valid conclusions to be reached. These experiments had to be discontinued after only two seasons, but in view of the results obtained it was judged desirable to put them on record and to draw the conclusions stated with the necessary reserve.

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NOTE ON A CASE OF CHICK-GROWTH DEPRESSION CAUSED BY A DETERGENT

I. ASCARELLI

(*Faculty of Agriculture, Hebrew University, Rehovot, Israel*)

Summary

It was shown by a chick-growth experiment that the addition of a commercial detergent to chick mashes caused a growth depression. Growth depression was also produced by the addition of the detergent to a mash enriched by an antibiotic.

FOLLOWING Ely's [1] first observation that 'surprisingly many commercial preparations for home laundry and dishwashing use are among the active types of surfactants that produce an increased growth response in chickens', many reports have been published on the action of surfactants as growth stimulators in different domestic animals. Conflicting results are reported by different authors.

Ely and Schott [2] confirmed the previous report [1]: among eight products tried four were judged 'rather active growth stimulators' giving an average growth increase of 7 per cent. at 12 weeks of age. March *et al.* [3] compared two surface active agents (Tween 80 and Santomerse 80) with antibiotics in different diets and found a growth stimulation in most cases, there being also a case of additional stimulation in the presence of an antibiotic. An alkyl-aryl-sulphonate was tested by Almquist and Merrit [4] and in three out of four comparisons there was a slight weight increase. The increases were not significant but it could be concluded that 'at least, the detergent was not toxic'.

Various synthetic detergents gave no response in Branion and Hill's [5] experiments and ten other detergents were found inactive by Snyder *et al.* [6]: one of the detergents was tested by the latter workers up to 10 weeks and gave some slight improvement which, however, was not significant.

Experimental

In the present experiment a commercial product (Tasbinol 300A) was tested. This product is a mixture of a non-ionic (fatty-acid-amide condensate) detergent with 10 per cent. of an anionic (dodecyl-benzene-sulphonate) one. It was tested at three levels: 0·25, 0·5, 1 per cent. in comparison with the growth stimulation produced by aureomycin (Aurofac). Each group consisted of forty newly hatched New Hampshire × White Leghorn chickens, housed in wire-floored battery brooders. The battery room has been in use for 20 years. The chickens were weighed in groups at weekly intervals and individually at the end of the experiment. The percentage composition of the diet was: ground barley 15, ground maize 25·25, wheat bran 20, groundnut meal 20, dried skimmed milk 5, fish meal 7·5, lucerne meal 4, ground oyster shell 2, dicalcium phosphate 0·75, manganized salt 0·5. The diet was supplemented with 500 I.U. vitamin A per 100 gm., 100 I.C.U. vitamin D_3

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per 100 gm., 3 gm. riboflavin per ton, 11 gm. pantothenic acid per ton, and 5 mgm. vitamin B_{12} per ton. The diet contained, by analysis, in percentages, 23·6 protein, 7·5 fibre, 2·4 calcium, and 0·9 phosphorus. All diets were fed *ad libitum*.

Final individual weights were statistically analysed.

Results and Discussion

The average weights at 4 and 6 weeks and the feed/gain ratios for the different groups are given in Table 1. It is quite apparent that no stimulation of growth was given by the detergent. On the contrary, growth was apparently depressed to a certain extent in all detergent-fed groups.

TABLE 1. *Average Weights of Chicks (gm.) at 4 and 6 Weeks and Feed/Gain Ratios*

Supplement	*Male*		*Female*		*Feed/gain ratios*
	4 weeks	*6 weeks*	*4 weeks*	*6 weeks*	
None (Control) . .	265	511±15·2	246	450±16·2	3·07
Detergent 0·25% . .	265	498±17·5	232	431±9·5	3·13
Detergent 0·5% . .	259	489±13·8	219	423±10·5	3·14
Detergent 1·0% . .	264	475±14·7	215	376±13·5†	3·04
Aureomycin 10 gm./ton .	312	586±13·0†	283	525±7·9†	2·95
Aureomycin 10 gm./ton + detergent 0·5% . .	307	571±9·2†	284	492±9·9	2·88

† Highly significant difference from control (P = 0·01).

This depression was not significant in any of the male groups and significant only at the 1 per cent. detergent level in the female groups. However, it is remarkable that the apparent depression, though generally not reaching statistical significance, was always proportional to the level of detergent fed. The addition of the detergent produced the same growth depression with the antibiotic-enriched ration and the basal ration.

The response of chickens to detergents is claimed to be dependent on the duration of the experiment, since the effect of surface-active agents has been shown to begin after the fourth week [6]. In the present experiment the depression of growth was clearly apparent and was becoming more marked every week. The experiment was therefore terminated after 6 weeks.

The depressing action of the detergent tested seems to be an intrinsic character and not to be dependent only on the level at which it was fed, even the lowest level (0·25) per cent. having caused an apparent depression.

The contrast between the stimulation by aureomycin and the depression by the detergent gives no support to either of the two theories of surfactants action (the anti-infective and the 'wetting' theory) proposed by Ely and Schott [2] and discussed by Branion and Hill [5]. Antibiotics failed to give an increased-growth response in Branion and Hill's experiments. It was therefore not possible, under their experimental

conditions, to prove the assumption that the same mechanism is responsible for the action of detergents and of antibiotics.

In the present experiment, the growth of the aureomycin group being statistically different from that of the basal group, it is to be presumed that the battery room was 'infected', and it is demonstrated that a better growth could be supported. The feed-conversion data are in agreement with the growth data, the feed/gain ratios being generally higher in the detergent-fed, more slowly-growing groups and lower in the aureomycin-fed, faster-growing groups. No better absorption is therefore demonstrated through the action of the tested detergent.

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STUDIES OF THE GROWTH OF CEREALS ON SEED-BEDS PREPARED BY DRY-SIEVING OF THE SOIL

II. POST-EMERGENCE SURVIVAL AND DEVELOPMENT

R. S. EDWARDS

(*Department of Agriculture, University College of Wales, Aberystwyth*)

WITH PLATES 4, 5, AND 6

Summary

The overwinter survival of S. 172 winter oats, sown at three different dates in autumn on seed-beds made up of various sieved soil separates at two degrees of consolidation, has been studied.

Attention is drawn to the special importance of frost-heaving as a factor influencing overwinter survival of the plants. In these experiments late sowing and fine seed-beds were shown to be associated with high plant mortality through frost-heaving. There is some evidence which suggests that, for plants from late autumn sowings, survival under conditions of severe frost-heaving is higher on plots which have been consolidated at sowing time.

The survival of spring-sown Spratt Archer barley on similar plots was also studied. Of the plants which emerged, a high percentage survived on all treatments. In one year only was there a significant difference in survival rate attributable to the soil treatment. In this case the finest seed-bed carried the greatest number of surviving plants.

The number of tillers per plant as a measure of plant development and vigour is also considered. This character did not appear to be responsive to the treatments applied. Such differences as did emerge favoured fine seed-beds.

THE first paper in this series [1] described the methods of plot layout and sowing and presented the results of observations of the emergence of Spratt Archer barley and S. 172 winter oats on sieved seed-beds between the years 1951 and 1956. Those results which relate to the survival and development of the plants during the period between emergence and harvest constitute the subject-matter of this paper. The experiments dealt with are the main ones carried out from 1954 to 1956; data from the pilot experiments which were considered in the previous paper, have been omitted; those from the 1951 experiment because the disparity of plant numbers on the various treatments, due to pest attack, was too great to give reliable results; those from the 1953 experiment because the plants were killed by frost damage.

The Survival of Plants

In his studies on the survival of winter wheat, Engledow [2] divided the period from emergence to harvest into two parts, using the stage in the development of the plant when the tiller counts were taken as the end of the first part and the beginning of the second. Survival counts were taken at that time and at harvest. He found that the great majority of the plant deaths took place, as might be expected, in the first phase of

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development, i.e. that the difference between plant numbers at tiller count and at harvest was very small unless some accident (such as rabbit damage) supervened. This has also been found to be true in all the experiments here described (accidental destruction having been avoided by adequate protection of the plots). In consequence, in so far as plant survival is concerned, attention is focused on the period up to the time of tiller counting.

Autumn-sown S. 172 Oats

In the autumn-sown experiments, a plant count was taken in April (at the same time as the tiller counts were made) when winter was over and no further frost damage might be reasonably expected. This count gave, therefore, an estimate of the overwinter survival of these plants. This proved to be very interesting and, as the two seasons 1954–5 and 1955–6 differed widely from one another, each will be dealt with separately in the first instance.

Winter 1954–5. In February 1955 a spell of severe frost occurred and its effects on the experiment sown during the previous autumn were unexpected. It was observed that the degree of frost-heaving at the surfaces of the various sieved soil separates was markedly different and that the reaction of the plants to this differential heaving varied according to the date at which they had been sown. Those plants which had been sown in September appeared to be undamaged on all plots regardless of soil-separate aggregate size. Plants sown in October showed more signs of damage but this was severe only on the plots made up of the finest separates (those which had passed a 1-mm. screen). On the November sowings the plants in these finest-structured soils were heaved, in many instances, completely out of the soil—their sheath bases and roots exposed. On the remaining coarser plots of this sowing damage was much less severe though some heaving had occurred. See Fig. 1, Plate 4.

These visual observations were confirmed in the subsequent plant-survival counts. Of the plants which emerged on all plots in the autumn 14·6 per cent. had died by the time of the April count. The distribution of survivors among the various treatments is given below. Analysis of covariance has been applied to these data in order that the survivor counts might be corrected for the different numbers of plants which had originally emerged. The comparison of the error regression for sub-plots with the deviations from this regression showed the error regression to be highly significant, $F = 8{\cdot}4$. Correction of the treatment sums of squares by removal of the regression sums of squares was then made and the summary of these analyses is presented in Table 1.

It will be noted that covariance has not been applied to data for whole plots with the object of correcting the 'time-of-sowing' treatment. In this case the number of degrees of freedom for the whole plot error is too small to make the technique worth while.

All the treatments which had a significant effect on plant survival in the April counts remain significant after the effect of various initial population has been taken into account, excepting the consolidation treatment. Here it appeared that the number of surviving plants on the

unconsolidated plots was significantly higher than on the consolidated plots. This difference disappeared, however, when allowance had been made for the higher number of plants which initially emerged on unconsolidated plots.

Tables 2 and 3 show the means relevant to the significant items in Table 1.

TABLE 1. *Effect of Time of Sowing, Soil-separate Aggregate Size and Consolidation on the Overwinter Survival of S. 172 Winter Oats (1954–5)*

	A Plants emerged			*B* Plants surviving in April			Analysis of *B* corrected for *A*		
Component	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*
Time	2	1,125·6	68·2*	2	1,337·3	87·9*	..	..	..
Replicates	1	1·4	..	1	4·5	..	..	..	..
Error (*a*)	2	16·5	..	2	15·2	..	..	..	..
Soil sep. size	5	197·5	13·9†	5	356·9	10·0†	5	401·3	13·8†
Consolidation	1	32·1	n.s.	1	168·0	4·7*	1	73·7	n.s.
Soil/consol.	5	27·6	n.s.	5	36·6	n.s.	5	26·8	n.s.
Time/soil	10	59·6	4·2†	10	942·6	26·5†	10	755·0	25·9†
Time/consol.	2	40·6	n.s.	2	62·1	n.s.	2	21·5	n.s.
Time/soil/consol.	10	48·9	3·4†	10	57·6	n.s.	10	27·6	n.s.
Error (*b*)	33	14·2	..	33	35·6	..	32	29·1	..

* Significant at P = 0·05. † Significant at P = 0·01. n.s. not significant.

TABLE 2. *Effect of Time of Sowing on the Overwinter Survival of S. 172 Winter Oats, 1954–5 (Means of 24 Plots)*

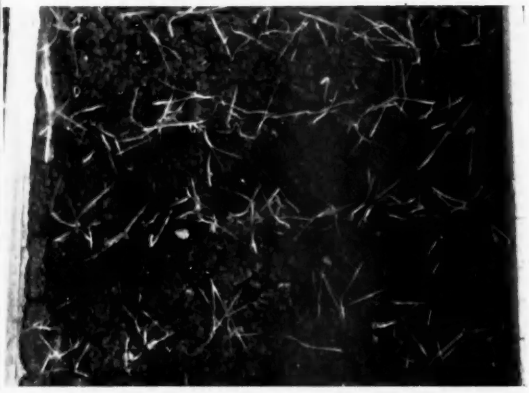
Time of sowing	*Sept.*	*Oct.*	*Nov.*	*Least sign. difference* $P = 0·01$	*Least sign. difference* $P = 0·05$
Plants emerged* per plot	83·9	96·7	94·7	..	5·03
Plants survived (April) per plot	70·8	85·7	78·8	..	7·40

*100 seeds were sown in each plot (excluding guard rows) in all experiments [1].

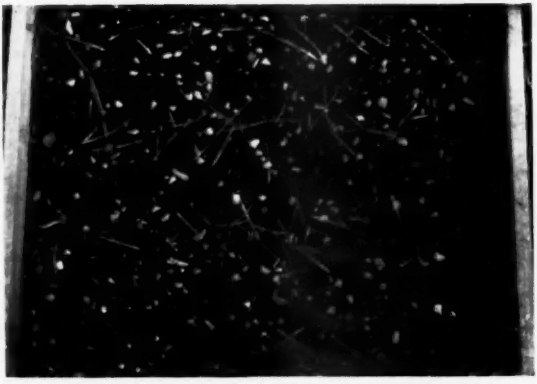
Though substantial losses of plants occurred in all the time-of-sowing categories, these losses were heaviest in the latest sowing. From observations already mentioned it is certain that the bulk of the losses sustained by the October and November sowings were the result of frost-heaving. This is not believed to be true of the September sowing. For reasons unknown these plots gave a lower percentage emergence than the other two sowings, and contained a number of weakly plants which probably succumbed during the autumn as they suffered severe competition from the strong pre-winter growth of their neighbours. From data available this suggestion cannot be proved but examination of the early-sown plots after the frost period showed practically no damage and the losses revealed by the April count were a surprise.

Table 3 demonstrates quite clearly that losses were highest on the finest plots and that there was no significant difference in the losses

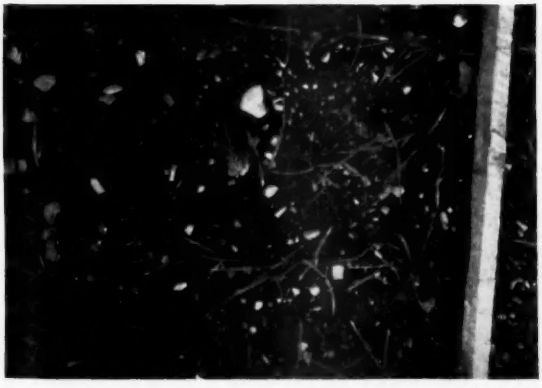
Sown November 1954
Photographed 20 March 1955



a. SEPARATE < 1 mm.
Severe damage—bulb & roots exposed in many plants



b. SEPARATE $\frac{3}{8}''$–$\frac{1}{2}''$
Little apparent damage



c. UNSIEVED SOIL
Slight damage—a few plants showing white leaf sheaths

FIG. 1. The effect of frost-heaving on plants of S. 172 winter oats sown in November in seed-beds made up of various sieved soil separates

TABLE 3. *Effect of Soil-separate Aggregate Size on the Overwinter Survival of S. 172 Winter Oats, 1954–5 (Means of 12 plots)*

Column no.	*1*	*2*	*3*	*4*	*5*	*6*	*Least sign. difference*	
Soil-separate aggregate size	*< 1 mm.*	*1 mm.–1/8″*	*1/8″–1/4″*	*1/4″–3/8″*	*3/8″–1/2″*	*Unsieved*	*P = 0·01*	*P = 0·05*
A. Plants emerged per plot .	97·6	94·6	92·7	90·5	86·2	89·2	4·00	3·08
B. Plants survived (April) per plot . .	68·2	81·7	83·4	80·7	77·0	79·4	6·34	4·88
B corrected for A	64·0	79·7	82·8	81·6	81·0	81·3	(*a*)	..

(*a*) L.S.D. for corrected means col. 1–col. 6, 7·88 (P = 0·01).
Cols. 2–6 do not differ significantly from each other but all differ highly significantly from col. 1.

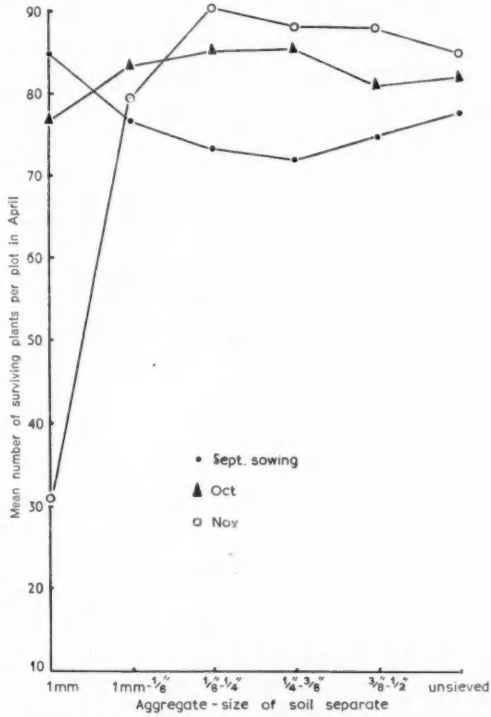


FIG. 2. The effect of time sowing and aggregate size of soil separate on the overwinter survival of S. 172 oats 1954–5 (each point is a mean of 4 plots).

between any of the other aggregate sizes. This confirms the visual appraisal of damage already recorded.

The interaction between time of sowing and soil-separate aggregate size is illustrated graphically in Fig. 2. The vulnerability to damage by

frost-heaving of plants sown late on fine seed-beds is clearly shown. The graph for the September sowing, which shows the number of survivors in April (corrected for initial number of plants) on the various aggregate sizes, lends some support to the suggestion already made concerning the timing of the plant deaths on this sowing. It shows that the highest survival rate was on fine seed-beds and the lowest on coarse ones, which makes it improbable that frost-heaving was responsible for the losses on plots of this sowing.

Winter 1955–6. The above results focused attention on the importance of differential frost-heaving in the various seed-beds as a factor influencing the survival of the autumn-sown oats. A similar experiment was laid down in autumn 1955 in the hope that confirmatory results might be forthcoming. Very severe frosts did in fact occur in February 1956—much more severe than those of the previous winter and in a different time sequence. The soil temperatures at 4-in. depth and the rainfall in inches over the winter period are given in Fig. 3.

Three major differences may be observed between the conditions in the two years which, it is believed, may account for differences in plant survival in the two seasons, viz.

(*a*) The soil temperatures reached lower levels in 1956.

(*b*) The week preceding the onset of severe frost was much wetter in 1956 than the corresponding week in 1955.

(*c*) Whereas the period of severe frost was continuous in 1955 from 11 February to 22 February (apart from minor fluctuations) the cold weather in 1956 was in two periods. The first, from 1 February to 3 February (when the grass minimum reached 9° F. on three successive nights) was followed by a rapid thaw which lasted until February 10 and was then succeeded by another very cold spell.

The reaction of the plants to these conditions is discussed later in this paper in the light of previous experimental work on frost-heaving.

The plots were observed daily throughout the cold spells of 1956; at the time of the temporary thaw, i.e. 3–10 February, the type of damage which was expected had occurred in the later sowings. Photographs taken at that time are reproduced in Figs. 4 and 5, Plates 5 and 6, and show that extensive damage was suffered by plants on the finest seed-beds only. The heaved soils slumped during this thaw and were heaved again by the second spell of frost which followed. This sequence had disastrous effects on all the plots of the October and November sowings, destroying plants extensively on all aggregate sizes of soil separate. In fact, at the end of the winter, the finest-structured soils, which had initially suffered most, were often better populated than some of the coarser plots because it seemed that heaved plants were better able to recover on the finest-structured soils. This recovery of heaved plants on fine-structured soils had been apparent also in the previous year and had made the losses (heavy as they were) lighter than they would otherwise have been.

Data obtained from the April count of surviving plants on the plots sown in autumn 1955 were analysed as before. A summary of the analyses is given in Table 4.

When this table is compared with Table 1 it is seen that, once again, sowing date and aggregate size of soil separate have strongly influenced the survival of plants. The chief point of difference is that, from Table 4, it would seem that the consolidation treatment has had an important

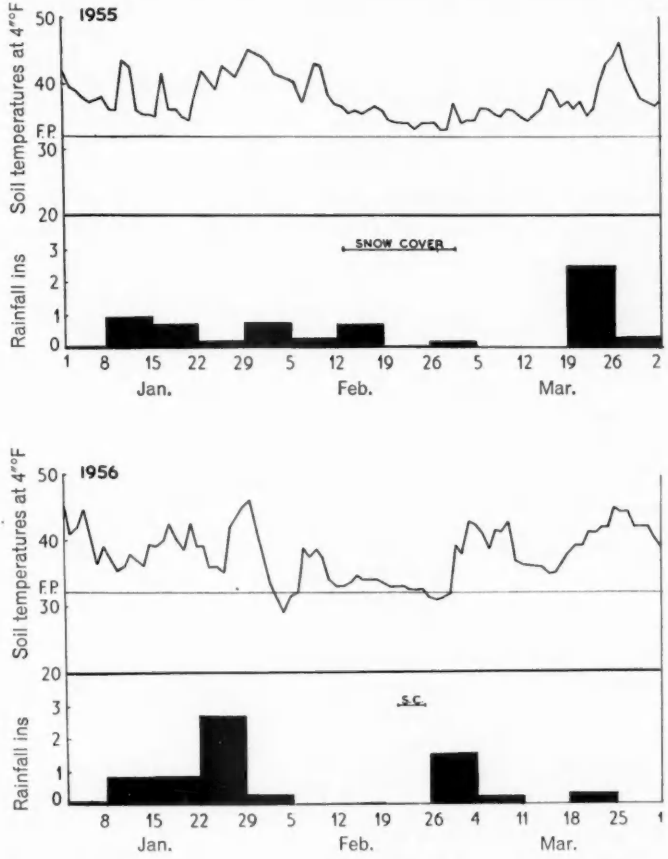


FIG. 3. Daily soil temperature at 4-in. depth and weekly rainfall during the months Jan., Feb., March, 1956.

effect on plant survival which was not apparent in the previous year. Tables 5, 6, and 7 give the mean plot values relating to the significant items in Table 4.

Table 5 shows that: (*a*) Emergence was much more variable than in the previous year (see Table 2); (*b*) the mortality in the September sowing was similar to that which occurred in the corresponding sowing of the previous year, i.e. about 11 per cent.; (*c*) the later sowings suffered

very heavy losses, around 60–70 per cent. of the plants which had emerged. Most of this loss can be attributed to frost-heaving.

Table 6 is in sharp contrast to Table 3. Losses, which in the 1954

TABLE 4. *Effect of Time of Sowing, Soil-separate Aggregate Size, and Consolidation on the Overwinter Survival of S. 172 Winter Oats (1955–6)*

	A *Plants emerged*			*B* *Plants surviving in April*			*Analysis of B corrected for A*		
Component	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*
Time . .	2	7,186·5	n.s.	2	30,994·0	v. large†	2	..	..
Replicates .	1	566·8	n.s.	1	28·1	562·0†	1	..	..
Error (*a*) .	2	730·3	..	2	0·05	..	2	..	..
Soil-sep. size .	5	716·3	21·4†	5	117·4	n.s.	5	136·4	2·58*
Consolidation .	1	133·4	n.s.	1	445·0	7·0†	1	708·3	13·4*
Soil/consol. .	5	38·0	n.s.	5	28·3	n.s.	5	50·2	n.s.
Time/soil .	10	569·3	17·0†	10	236·5	3·7†	10	133·2	2·5*
Time/consol. .	2	37·4	n.s.	2	341·8	5·36†	2	341·1	6·5†
Time/soil/ consol. .	10	17·4	n.s.	10	92·8	n.s.	10	89·0	n.s.
Error (*b*) .	33	33·5	..	33	63·8	..	32	52·8	..

* Significant at P = 0·05. † Significant at P = 0·01. n.s. = not significant.

TABLE 5. *Effect of Time of Sowing on the Overwinter Survival of S. 172 Winter Oats, 1955–6 (Means of 24 Plots)*

Time of sowing	*Sept.*	*Oct.*	*Nov.*	*Least sign. difference* $P = 0·01$	*Least sign. difference* $P = 0·05$
Plants emerged per plot .	96·8	64·8	92·3	n.s.	n.s.
Plants survived (April) per plot . . .	86·1	17·7	32·6	6·25	..

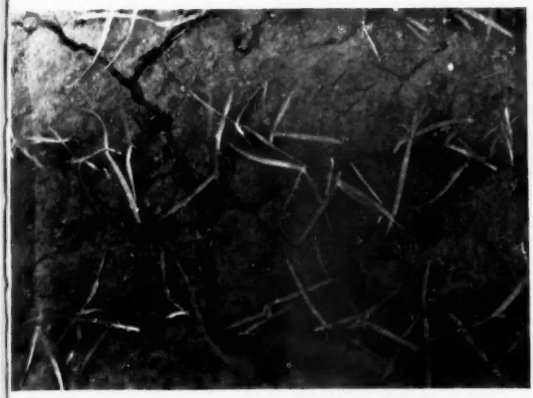
TABLE 6. *Effect of Soil-separate Aggregate Size on the Overwinter Survival of S. 172 Winter Oats, 1955–6 (Means of 12 Plots)*

Column no.	*1*	*2*	*3*	*4*	*5*	*6*	*Least sign. difference*	
Soil-separate aggregate size	*< 1 mm.*	*1 mm.–* $\frac{1}{8}$″	$\frac{1}{8}$″–$\frac{1}{4}$″	$\frac{1}{4}$″–$\frac{3}{8}$″	$\frac{3}{8}$″–$\frac{1}{2}$″	*Unsieved*	$P = 0·01$	$P = 0·05$
A. Plants emerged per plot .	94·8	86·5	88·9	84·9	80·5	72·2	6·14	4·72
B. Plants survived (April) per plot . .	49·9	44·7	45·2	40·8	48·0	44·2	n.s.	n.s.
B corrected for A	43·7	43·5	42·6	40·6	50·5	51·8	..	(*a*)

(*a*) L.S.D. (P = 0·05) for corrected means col. 4–col. 6 = 8·12, col. 4–col. 5 = 6·24.

sowings were mostly confined to the finest soil-aggregate size, have here extended down the range of soil-aggregate sizes. Nevertheless, it is noteworthy that (after allowance has been made for initial numbers) the coarsest separate, and unsieved soil—which contained a fair proportion of larger material—carried the greatest number of surviving plants.

Sown November 1955
Photographed 7 February 1956



a. SEPARATE < 1 mm.
Fairly severe damage—slumping of soil has not yet occurred

b. SEPARATE $\frac{3}{8}$"–$\frac{1}{2}$"
No apparent damage

c. UNSIEVED SOIL
No apparent damage

FIG. 4. The effect of frost-heaving on plants of S. 172 winter oats sown in November in seed-beds made up of various sieved soil separates

Sown November 1955
Photographed 5 March 1956

a. SEPARATE < 1 mm.
Majority of plants killed. Soil has slumped after heaving

b. SEPARATE $\frac{3}{8}''-\frac{1}{2}''$
Damage less severe than in *a*.
Much less deformation of soil surface

c. SEPARATE 1 mm.–$\frac{1}{8}''$
Damage more severe than in *b* but less than in *g*.
Surface less deformed than in *g*

FIG. 5. The effect of frost-heaving on plants of S. 172 winter oats sown in November in seed-beds made up of various sieved soil separates

Firm seed-beds carried a higher population of surviving plants than loose seed-beds. The difference was accentuated when the higher initial number of plants on the latter was taken into account and reached a higher significance than $P = 0.01$. It seems possible that the better anchorage of the plants in firm seed-beds may have been responsible for this effect. That winter-sown plants survived better on firm seed-beds has also been noted by Aufhammer [3], while other workers [4] have found the amount of frost-heaving to be greater on loose than on compacted soils. Whether the higher survival of plants on firm seed-beds was due to better anchorage or to less lift on such seed-beds or to a combination of both factors must therefore remain undecided.

TABLE 7. *Effect of Consolidation of Plots at Sowing Time on the Overwinter Survival of S. 172 Winter Oats, 1955–6 (Means of 36 Plots)*

Seed-bed treatment	*Not consolidated*	*Consolidated*	*Least sign. difference*	
			$P = 0.01$	$P = 0.05$
A. Plants emerged, per plot	86·0	83·3	n.s.	n.s.
B. Plants survived (April) per plot . . .	43·0	48·0	..	3·76
B corrected for A . .	42·2	48·8	4·71	..

It is of some interest to note that, in the previous winter, the consolidated plots with the finest-structured soil (which suffered the greatest heaving) carried more surviving plants than the unconsolidated plots; whereas on all other soil-aggregate sizes the reverse was true. This interaction did not, however, reach significant levels.

From the graphs in Fig. 6 it may be said that, whereas survival rates were relatively higher on fine plots when autumn sowing was early the rate was relatively higher on coarse plots when sowing was late. Though some of the data from the November sowing are aberrant the interaction reached significance and appears to justify the above interpretation.

Fig. 7 shows clearly that, in this instance, the later the date of autumn sowing the greater the disparity in the number of plant survivors on consolidated as compared with unconsolidated plots, the greatest number being found on the former. A possible interpretation of this observation is that when the oats are sown early in autumn they have time to develop large root systems and are adequately anchored in both firm and loose seed-beds whereas with later sowings plants have weaker root systems and firm seed-beds give better purchase.

Discussion of winter results. It is obvious that the heaving effect of frost outweighs all other factors in this discussion of winter survival. The phenomenon of frost-heave has been recognized for a long time and is of interest to engineers, road-research workers, and others beside agriculturalists [4, 5, 6, 7, 8, 9, 10, 11, 12]. At one time the lift was attributed to the simple expansion which accompanies the change from water to ice. That this view was incorrect and failed to account for the magnitude of heaving was stated by Bouyoucos and McCool [5] and by Taber [6]. According to these workers lift is caused by the growth of ice crystals

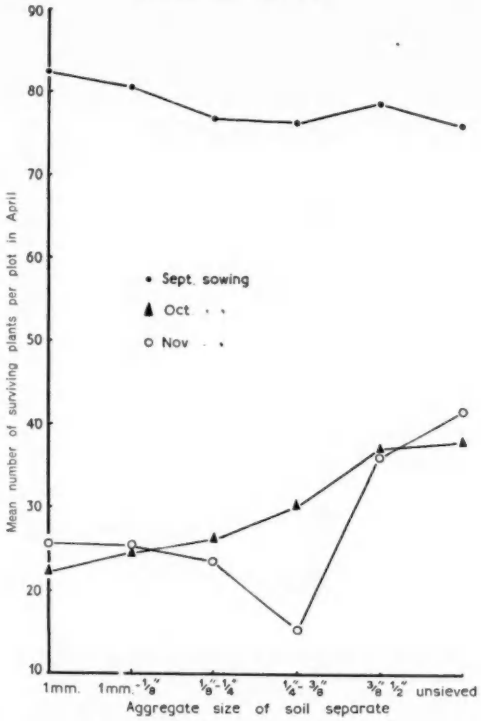


FIG. 6. The effect of time of sowing and aggregate size of soil separate on the overwinter survival of S. 172 oats, 1955–6 (each point is a mean of 4 plots).

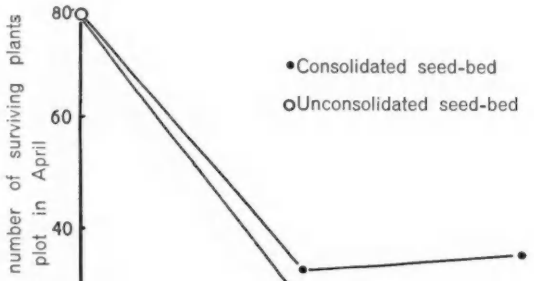


FIG. 7. The effect of time of sowing and seed-bed consolidation on the overwinter survival of S. 172 oats, 1955–6 (each point is a mean of 12 plots).

in a direction normal to the freezing isotherm, i.e. upward from the soil surface. The crystals draw water from the lower layers of the soil by forces of molecular cohesion which are of great magnitude. Taber found that the following factors determined the extent of lift under laboratory conditions:

(*a*) Size of soil particles—fine particles heaved more than coarse ones.
(*b*) Pore-size distribution (this is controlled to a great extent by *a*)—small pores gave a better water supply to the growing crystals and therefore more heaving.
(*c*) The quantity of water available—it is obvious that to accumulate a great thickness of ice a large amount of water is required.
(*d*) The rate of cooling—this affected heaving on some soils but not on others. Other workers [11] claim that it has no effect.
(*e*) The sequence of frost and thaw—freezing after a thaw, which has liberated water raised by previous frost, produced maximum heave.

Examination of these factors shows that *a* and *b* can be applied directly as possible explanations for the greater degree of heaving found on the plots made up of separates with aggregate sizes less than 1 mm. Data on pore-space distribution in these separates will be discussed later in this series when it will be shown (as might be expected) that the proportion of small pores is much higher in the finest seed-beds than in any of the others. Factor *c* probably applies but as there are no data available on the soil-moisture content at the commencement of the frost this must be merely a likely deduction from *b*, bearing in mind also the rainfall conditions at the time.

In seeking an explanation of the greater damage suffered by the plants in 1956 when compared with that suffered in the previous year factors *c* and *e* would seem to be of importance. The soil was much wetter in 1956 and this alone would cause more heaving. The sequence frost–thaw–frost in 1956 was also, most probably, extremely damaging. Not only was water brought to the surface, thawed, and refrozen, causing maximum lift, but in addition, the intervening slumping of the raised surface during the thaw allowed the ice to take a second grip of the plants at a lower point than before.

Another observation should be mentioned here. It was noticed that heaving was most severe at the centre of the plot and diminished towards the sides. This was reflected in the survival of plants, those in the discard rows being less affected than those in centre rows. It was at first thought that the edges of the plot offered some protection and that this accounted for the phenomenon. Closer observation revealed, however, that an arching effect was responsible. The firm edges of the plots acted as abutments and the frozen surface of the plot appeared to attempt to expand laterally. Being unable to do so it arched or buckled, causing more lift in the centre than at the edges. It is possible that local points of surface anchorage may cause analogous behaviour in the field and it is hoped to investigate this point in the future.

The farming precept which says that autumn seed-beds should be

rough (for which precept agricultural scientists have proposed many explanations) thus receives considerable support from these studies. It must, however, be borne in mind that a fine seed-bed in the agricultural sense and a fine seed-bed produced by sieving need not be directly comparable.

TABLE 8. *Percentage of Emerged Plants which Survived at the time of Tiller Counting (Means of 72 Plots)*

Year of sowing	*1954*		*1955*		*1956*
Crop	*Spring barley*	*Winter oats*	*Spring barley*	*Winter oats*	*Spring barley*
Surviving plants as % of emerged plants	97·5	75·4	97·8	53·7	97·0*

* Mean of 36 plots.

TABLE 9. *Effect of Time of Sowing, Soil-separate Aggregate size, and Consolidation on the Survival of Spratt Archer Barley, 1955*

Summary of Analyses of Variance

	A *Plants emerged*			*B* *Plants surviving at Tiller count*			*Analysis of B corrected for A*		
Component	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*
Time	2	201·3	183·0†	2	146·4	n.s.	2	..	..
Replicates	1	1·3	n.s.	1	3·5	..	1	..	..
Error (*a*)	2	1·1	..	2	27·3	..	2	..	..
Soil-separate aggregate size	5	114·1	13·3†	5	147·2	20·4†	5	26·3	6·3†
Consolidation	1	0·4	n.s.	1	2·0	n.s.	1	0·9	n.s.
Soil/consol.	5	3·5	n.s.	5	3·7	n.s.	5	4·4	n.s.
Time/soil	10	30·6	3·6†	10	14·5	n.s.	10	8·3	n.s.
Time/consol.	2	4·4	n.s.	2	5·3	n.s.	2	2·3	n.s.
Time/soil/consol.	10	1·5	n.s.	10	1·4	n.s.	10	1·9	n.s.
Error (*b*)	33	8·6	..	33	7·2	..	32	4·2	..

† Significant at P = 0·01. n.s. = not significant.

Spring-sown Spratt Archer Barley

The survival data obtained from counts of spring-sown barley are of little interest when compared with those from the autumn-sown experiments. In all the spring experiments mortality was very low as shown in Table 8.

Only in the spring 1955 experiment was any differential survival of plants observed on the various treatments. The results for this experiment are shown in Tables 9, 10, and 11.

Table 10 shows that the greatest mortality was suffered by the latest sowing. The March sowing shows a slightly higher number of survivors than of original plants. This was caused by the late emergence of one or two weakly plants after the final emergence counts had been taken.

In this experiment there was a higher rate of plant survivals on fine tilths than on coarse ones. Survival on all seed-beds was satisfactory in that ample plants remained to produce a crop.

All these spring experiments may be briefly summed up by stating that survival rate was high under all the treatments applied. Any differences observed were small.

TABLE 10. *Effect of Time of Sowing on the Survival of Spratt Archer Barley, 1955 (Means of 24 Plots)*

Time of sowing	*March*	*April*	*May*	*Least sign. difference*	
				$P = 0.01$	$P = 0.05$
Plants emerged per plot	94·6	91·7	97·5	3·06	1·33
Plants survived per plot	94·8	90·0	92·8	n.s.	n.s.

TABLE 11. *Effect of Soil-separate Aggregate Size on the Survival of Spratt Archer Barley, 1955 (Means of 12 plots)*

Column no.	*1*	*2*	*3*	*4*	*5*	*6*	*Least sign. difference*	
Soil-separate aggregate size	*<mm.*	*1 mm.–⅛″*	*⅛″–¼″*	*¼″–⅜″*	*⅜″–½″*	*Unsieved*	$P = 0.01$	$P = 0.05$
A. Plants emerged per plot	97·8	96·7	95·9	95·2	92·3	89·6	3·12	2·40
B. Plants survived per plot	97·0	94·4	95·1	91·5	89·1	88·2	2·86	2·20
B corrected for A	95·1	93·1	94·3	91·1	90·5	91·2	(*a*)	..

(*a*) L.S.D. ($P = 0.01$) for corrected means col. 1–col. 6 = 3·60; col. 3–col. 5 = 2·44.

The Number of Tillers per Plant

The numbers of tillers produced by the plants of both winter oats and spring barley, in one inner row on each plot, chosen at random, were counted once during their development. This method of assessing the relative vigour of growth has been used extensively but is open to criticism. Engledow [13] has drawn attention to one of the biggest drawbacks of the method thus: 'It was impossible to record the sizes of tillers and equality in number often accompanied disparity in size.' Nevertheless, with the facilities available no other method (e.g. leaf count and measurement) was practicable. The results of the tiller counts appear below. It was the aim to count the tillers at a time when most plants had from three to five tillers. For all the autumn-sown plots a single count taken in April satisfied this requirement. With spring barley, however, separate counting dates were necessary for the three sowings since, for example, the first sowing might be in the three-tillers phase when the third sowing had scarcely emerged. In consequence of this method of counting, significant differences attributable to the 'Time-of-Sowing' treatment for spring plots are meaningless, since they merely show that the operator was incapable of visually assessing when the plants had reached equivalent stages of development on the different sowings.

It is well established that the profusion of tillering is affected by the amount of space available to the plant. Thus plots which had low plant populations would tend to have more tillers per plant, this effect tending to mask differences directly due to the plot treatments. Covariance was therefore applied to the 'tillers-per-plant' data in order to allow for plant-population differences.

Experiments on Winter Oats

A summary of the analyses of variance for winter oats sown in 1954 appears in Table 12.

It will be seen that, in this instance, the significant variance in tiller number due to soil-separate aggregate size and to time of sowing/soil-separate size interaction is reduced to insignificance when the correction for population differences is made. The high negative correlation between number of plants and number of tillers is clearly illustrated in Fig. 8.

TABLE 12. *Effect of Time of Sowing, Soil-separate Aggregate Size, and Consolidation on the Number of Tillers per Plant in S. 172 Winter Oats (1954–5)*

	A Number of plants			*B* Tillers per plant			*Analysis of B corrected for A*		
Component	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*
Time	2	90·5	69·6*	2	0·98	n.s.	2	..	..
Replicates	1	1·4	n.s.	1	0·03	n.s.	1	..	..
Error (*a*)	2	1·3	..	2	0·095	..	2	..	..
Soil-separate size	5	17·3	3·97*	5	0·66	4·7†	5	0·18	n.s.
Consolidation	1	29·4	6·7*	1	0·93	6·6*	1	0·13	n.s.
Soil/consol.	5	5·4	n.s.	5	0·04	n.s.	5	0·07	n.s.
Time/soil	10	51·4	11·9†	10	0·53	3·8†	10	0·14	n.s.
Time/consol.	2	0·6	n.s.	2	0·20	n.s.	2	0·20	n.s.
Time/soil/consol.	10	4·7	n.s.	10	0·26	n.s.	10	0·14	n.s.
Error (*b*)	33	4·35	..	33	0·14	..	32	0·10	..

* Significant at P = 0·05. † Significant at P = 0·01. n.s. = not significant.

TABLE 13. *Effect of Soil-separate Aggregate Size and Consolidation on the Number of Tillers per Plant in S. 172 Winter Oats (1955–6)*

Summary of Analyses of Variance

	A Number of plants			*B* Number of tillers			*Analyses of B corrected for A*		
Component	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*
Replicates	1	0·1	n.s.	1	0·01	n.s.	1	0·01	n.s.
Soil-separate aggregate size	5	10·3	12·1†	5	0·30	3·3*	5	0·28	5·0*
Consolidation	1	0·4	n.s.	1	0·05	n.s.	1	0·02	n.s.
Soil/consol.	5	0·9	n.s.	5	0·18	n.s.	5	0·06	n.s.
Error	11	0·85	..	11	0·09	..	10	0·056	..

* Significant at P = 0·05. † Significant at P = 0·01. n.s. = not significant.

In the 1955 autumn experiment frost damage was so severe on the October and November sowings that the collection of data subsequent to the frost was confined to the twenty-four plots of the September sowing.

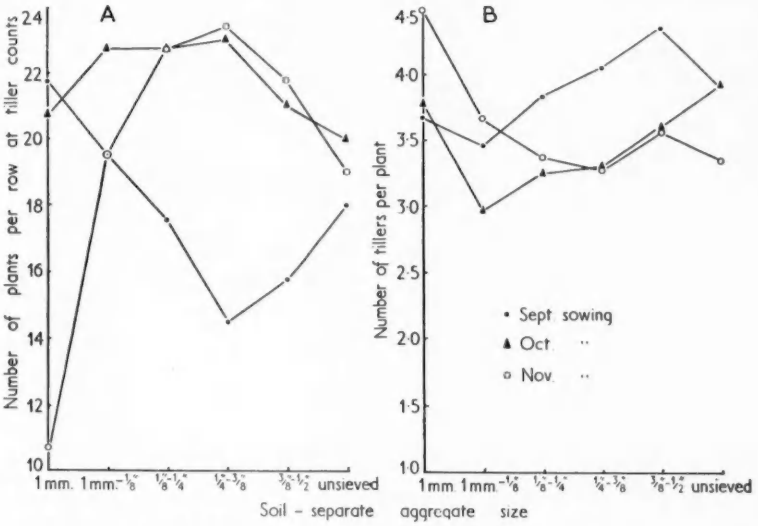


FIG. 8. The effect of time of sowing and aggregate size of soil separate on *A*, the number of plants per row at the time of tiller counts, *B*, the number of tillers per plant. S. 172 oats 1954–5 (each point is a mean of 4 plots).

TABLE 14. *Effect of Soil-separate Aggregate Size on the Number of Tillers per Plant of S. 172 Winter Oats, 1955–6 (Means of 4 Plots)*

Column	*1*	*2*	*3*	*4*	*5*	*6*	*Least sign. difference*	
Soil-separate aggregate size	*< 1mm.*	*1 mm.–⅛"*	*⅛"–¼"*	*¼"–⅜"*	*⅜"–½"*	*Unsieved*	*P = 0·01*	*P = 0·05*
A. Number of plants per row . .	23·0	23·0	23·0	20·2	20·2	19·7	2·03	1·43
B. Tillers per plant. .	4·75	4·22	4·12	4·50	4·37	4·80	..	0·47
B corrected for A	5·06	4·53	4·43	4·23	4·10	4·42	..	(*a*)

(*a*) L.S.D. (P = 0·05) for corrected means col. 1–col. 5 = 0·48. No other significant difference.

Here there is a residual significant difference attributable to the soil treatment after removal of the effect due to plant number. The means for the soil treatments are given in Table 14. The plants on the finest plots had more tillers than those on the coarser plots, but differences, though significant, were small.

Experiments on Spring Barley

No difference between the number of tillers per plant on the various treatments could be detected in 1954 nor in 1955. In 1956 the results shown in Tables 15 and 16 were obtained.

With a uniformly high plant population the regression of tillers per plant on number of plants was not significant; no correction could therefore be applied to the tiller counts.

The number of tillers per plant was higher on fine plots than on coarse ones.

TABLE 15. *Effect of Time of Sowing and Soil-separate Aggregate Size on the Number of Tillers per plant of Spratt Archer Barley (1956)*

Summary of Analyses of Variance

Component	*A* Number of plants			*B* Tillers per plant			*Analysis of B corrected for A*		
	DF	*VAR*	*F*	*DF*	*VAR*	*F*	*DF*	*VAR*	*F*
Time	2	0·1	n.s.	2	0·27	87·1*	2	..	..
Replicates	1	0·0	n.s.	1	0·16	52·5*	1	..	..
Error (*a*)	2	2·3	..	2	0·0031	..	2	..	..
Soil-separate aggregate size	5	16·8	4·9†	5	0·68	28·3†	5	Regression of B on A not significant	
Time/soil	10	1·4	n.s.	10	0·12	5·0†	10		
Error (*b*)	15	3·5	..	15	0·024	..	14		

* Significant at P = 0·05. † Significant at P = 0·01. n.s. = not significant.

TABLE 16. *Effect of Soil-separate Aggregate Size on the Number of Tillers per Plant of Spratt Archer Barley, 1956 (Means of 6 Plots)*

Soil-separate aggregate size	< 1 mm.	1 mm. – $\frac{1}{8}$″	$\frac{1}{8}$″–$\frac{1}{4}$″	$\frac{1}{4}$″–$\frac{3}{8}$″	$\frac{3}{8}$″–$\frac{1}{2}$″	*Unsieved*	*Least sign. difference*	
							P = 0·01	*P* = 0·05
Tillers per plants	3·52	2·94	3·18	2·92	2·54	3·25	0·27	0·19

Discussion on Tillering Data

So far as autumn-sown plots are concerned there are insufficient data from which to draw valid conclusions. The issue is complicated by the large differences in plant population caused by winter killing. What evidence there is points to a higher number of tillers per plant on fine plots, which is in accordance with visual appraisals of the relative vigour of the plants.

In discussing the spring barley plots mention must be made at this point of the weed problem. It was found that the sieving of the soil caused a redistribution of weed seeds, in particular of the seeds of *Stellaria media*—by far the most common weed on the experimental field. Where the plots were autumn-sown few weeds appeared and those that were present appeared to be evenly distributed. Even those plots which

carried low cereal populations did not become very weedy. In spring-sown plots, however, differential distribution of weeds became a serious menace since the effects were confounded with the soil treatments. A count taken sixteen days after sowing in May 1954 appears in Table 17.

This indicates that many seeds failed to pass the 1-mm. screen; weed population on the finest separate was low. Many seeds fall through larger screens until they reach the 1-mm. screen and pass out with the second-finest separate. In the 1954 and 1955 experiments, hand hoeing and pulling was resorted to on all plots and satisfactory control was achieved. It was felt, however, that the resulting disturbance of the soil surface was undesirable and that the weeds had probably competed to some degree before they were large enough to be removed thoroughly. As a check to this a smaller experiment, additional to the original programme, was sown

TABLE 17. *Effect of Soil-separate Aggregate Size on Number of Weed Seedlings per Plot, 1954 (Means of 12 Plots)*

Soil-separate aggregate size	*< 1 mm.*	*1 mm.–$\frac{1}{8}$″*	*$\frac{1}{8}$″–$\frac{1}{4}$″*	*$\frac{1}{4}$″–$\frac{3}{8}$″*	*$\frac{3}{8}$″–$\frac{1}{2}$″*	*Unsieved*	*Least sign. difference $P = 0{\cdot}01$*
Weed seedlings . .	27·0	95·2	38·2	36·3	29·9	40·2	6·58

in 1956 and the weeds sprayed with D.N.O.C. at a rate equivalent to 6 lb. of the activated sodium salt in 100 gallons of water per acre. At spraying the barley was in the three-leaf stage and the weeds very small. The result was, for all practical purposes, a 100 per cent. kill and the plots remained substantially weed-free until harvest. There was no apparent damage to the barley beyond slight scorching of the leaf tips from which the plants rapidly recovered.

A characteristic of the post-emergence data from the 1954 and 1955 experiments had been the poor showing of the 1 mm.–$\frac{1}{8}$ in. separate when compared with the immediately finer or coarser separates. This separate almost invariably gave lower yields of grain and straw than they did. It was felt that perhaps the large accumulation of weed seed and the resulting competition might be responsible for this depression in spite of the counter-measures taken. It is noteworthy, however, that the same trend appeared in 1956 when the weed factor was eliminated (see Table 16). This point will be pursued in the next paper, on harvest data, and some explanation offered in a later paper on certain physical characters of the sieved seed-beds. It must further be considered whether, as the 1956 experiment is the only spring-sown one showing significant differences in the number of tillers per plant, the spraying of weeds may have been responsible for this, though this is believed to be unlikely. A more likely explanation why fine seed-beds carried more tillers per plant in 1956 but not in 1954 and 1955 emerges when the rainfall data are examined.

Table 18 shows that the tillering period was much drier in 1956 than in the other years. It seems likely that under dry conditions the plants on the finest seed-beds benefited from the better water supply which

such a seed-bed would probably hold. Evidence to show that the finest seed-beds hold substantially more water at field capacity than the remaining seed-beds will be presented in a later paper.

TABLE 18. *Rainfall during the Tillering Phases of Spring Barley, 1954–6*

Dates	1954		1955		1956	
	May	*June*	*May*	*June*	*May*	*June*
Rainfall, inches . .	2·32	4·71	4·33	4·62	1·23	2·21

Conclusions

The most important general conclusions to be drawn from these studies of the behaviour of winter oats and spring barley between emergence and harvest may be briefly stated thus: Under the experimental conditions described plants on the finest seed-beds generally showed somewhat better growth than those on coarse ones. In the autumn-sown experiments on winter oats, however, any advantage in the growth of plants on fine seed-beds was negatived by the liability of the plants on these seed-beds to be killed by frost-heaving unless planted early.

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THE DIRECT EFFECT OF TROPICAL CLIMATE ON THE PERFORMANCE OF EUROPEAN-TYPE CATTLE

II. PRODUCTION

W. J. A. PAYNE[1] AND JOHN HANCOCK[2]

Summary

Eight sets of temperate-breed identical twin heifer calves were divided between Fiji and New Zealand. Feeding and management in the two countries were identical, the only major difference to which the animals were subjected being that of climate. The growth and production of the animals from the age of 7½ months to the end of their first lactation was followed in both countries. Differences in growth of the two groups were reported in a previous paper. This paper deals with the differences in production.

Unfortunately the production records of two sets of twins had to be omitted from the results as one heifer in each set suffered from ill health and had to be dried off prematurely.

Average milk production of the remaining six sets of twins was considerably higher in New Zealand (44 per cent.), as was butterfat production (56 per cent.), while solids-not-fat production was only slightly higher (19 per cent.). Butterfat percentage was higher in the milk of the New Zealand twins, but there were no real differences in the percentage of solids-not-fat of the milk of the Fiji and New Zealand twins. It may be concluded that the climate of Fiji adversely affected the production of a random sample of temperate-type milking cattle.

The twins in Fiji did not respond in a uniform manner to the stress of a tropical climate, as two of them produced at almost the same level as their co-twins in New Zealand, while the level of production of the other four was well below that of their co-twins. This suggests that there are profound differences in the reaction of individual temperate-type dairy cattle of the same breed to a tropical climate, and that these differences must be based at least in part on genetic differences between individuals.

The feed intake of the Fiji twins was lower than that of their co-twins in New Zealand, the major difference being a decrease in hay intake.

The water intake of the Fiji twins was considerably higher than that of their co-twins in New Zealand, and it was concluded that it is particularly necessary to provide adequate supplies of fresh drinking water to temperate-type milking cows in the tropics, and that estimates of water needs should not be based on temperate-zone standards.

The average daily rectal temperature and respiration rate of the Fiji twins was considerably above that of their co-twins in New Zealand. The experimental results suggest that considerable caution should be exercised in utilizing the magnitude of the rise in rectal temperature as a measure of the probable productivity of lactating temperate-type dairy animals in the tropics.

THIS is the second part of a co-operative study undertaken by the Departments of Agriculture of New Zealand and the Crown Colony of Fiji and begun in 1950. Eight sets of identical twin heifer calves, born and bred in New Zealand, were used as experimental material. When

[1] Department of Agriculture, Research Station, Sigatoka, Fiji.

[2] Formerly at Ruakura Animal Research Station, Animal Research Division, Department of Agriculture, New Zealand. Now at the International Bank of Reconstruction and Development, Washington, D.C., U.S.A.

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the calves were 7 months of age, the twin sets were divided, and the odd-numbered members of each set were imported into Fiji, while their even-numbered co-twins remained in New Zealand. In both countries the twins were fed and managed according to a prearranged plan so that the major environmental factors, with the exception of climate, should be as uniform as possible. The direct effect of a tropical climate on the growth of these animals has been reported in a previous paper [1], and this paper is concerned with the effect on production during the first lactation.

Experimental Details

Locality and Climate

Fiji. The Agricultural Station at Sigatoka, where half the experimental work was carried out, is situated at sea-level in latitude 18° S., longitude 178° E., on the south coast of the main island of the Fiji group, Viti Levu. Within Fiji, Sigatoka is considered to be in the 'dry' zone as the vegetation is of the savannah type and is not tropical rain forest, but on a world scale the climate would be classified as hot and humid. There is a well-defined wet season, lasting from December to April, but some rain usually falls every month. The wet season coincides with the hot season and the winter is relatively cool and dry.

New Zealand. Ruakura Animal Research Station, where the other half of the experimental work was carried out, is situated at an altitude of 130 ft. in latitude 38° S., longitude 175° E., in the North Island of New Zealand. The climate is temperate with a moderately high rainfall and high relative humidity. Fairly heavy night frosts occur frequently during the period mid-June to mid-August.

Details of the annual average maximum, minimum, and mean temperatures, relative humidity, absolute humidity, and total rainfall at both experimental centres for the period January 1951 to July 1952 are shown in Table 1. The mean temperatures are approximately 20° F.

TABLE 1. *Climatological Data for 1951 and January to July 1952*

	1951		*Jan.–July 1952*	
	Sigatoka	*Ruakura*	*Sigatoka*	*Ruakura*
Average maximum temperature (°F.)	83·9	64·6	85·5	65·0
Average minimum temperature (°F.)	68·2	44·1	70·0	45·2
Mean temperature (°F.)	76·0	54·2	77·7	55·1
Average relative humidity (per cent.)	79·9	84·0	80·3	84·9
Average absolute humidity (grains moisture per lb. dry air)	116·5	56·6	123·7	57·9
Total rainfall (in.)	64·6	41·5	47·3	24·0

lower at Ruakura. It will be also seen from Fig. 1 that maximum temperatures at Ruakura barely exceed minimum temperatures at Sigatoka at any time of the year. The annual and diurnal variations in temperature are greater at Ruakura than at Sigatoka. The rainfall is much greater at Sigatoka, and there is a well-defined wet season, but the effective rainfall may not be greater than at Ruakura. The relative

humidity is approximately the same at both centres, but the absolute humidity is much lower at Ruakura. In the first paper [1] the authors published 'climographs' constructed to show the difference between the two climates. These show clearly that the climates of Fiji and New Zealand are very different, the 'climograph' of Sigatoka resembling that of Calcutta. According to Wright [2] the climate in Calcutta is sufficiently

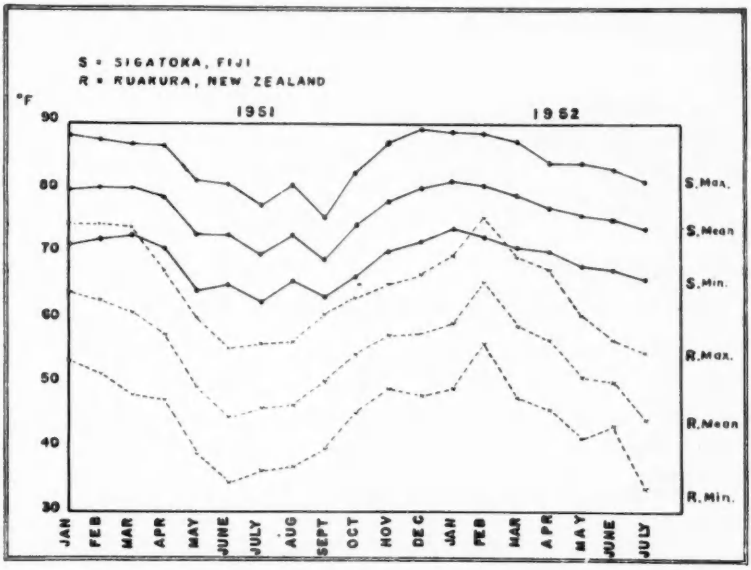

FIG. 1. Maximum, minimum, and mean temperatures at Sigatoka and Ruakura, 1951–2.

severe to cause dwarfing and low productivity even in indigenous tropical-type cattle, whereas it is generally considered that the climate of New Zealand is sufficiently favourable to permit the optimal growth and production of temperate-type cattle.

Animals

The eight sets (six grade Jersey, one grade Shorthorn, and one Jersey-Shorthorn) of identical twin heifers were selected from a herd of twenty-five sets, and although animals as much of an age as possible were selected, they may be considered to be a random sample of dairy cattle from the Waikato district of New Zealand. In the first paper [1] there is a description of the sets and photographs of representative sets at separation, one year later, and at the end of the first lactation. The odd-numbered animals were shipped to Fiji when they were approximately 7½ months old, the even-numbered animals remaining in New Zealand. On arrival in Fiji the animals were quarantined in Suva for ten days and finally arrived at Sigatoka a fortnight after they had left Ruakura.

Throughout this period they were fed on lucerne hay and barley meal, whereas in New Zealand they had been on pasture. The rigours of the voyage and the sudden change of diet and climate combined caused a sharp initial setback in the condition of the calves in Fiji.

Feeding

At both stations the heifers were run in yards that were always kept free of vegetation. At no time were they allowed out on pasture. In the yards shade, water (from automatic water troughs) and minerals, consisting of steamed bone flour and rock salt, were freely available. The minerals were not fed at first but were available after 12 February 1951 until the end of the experiment.

Twice a day, from 6 to 8 a.m. and from 3 to 5 p.m., the animals were brought into a shed to be fed in individual feeding bails. Concentrates were fed in a bucket placed in the feeding-box and hay was placed directly in the box. All feeds were weighed out and residues weighed back.

The general feeding plan before calving was to allow *ad lib.* intake of hay but to restrict concentrate intake to 1 per cent., of body-weight, but concentrate feeding was stopped at both stations for some two months prior to mating. The concentrate mixture fed throughout the period before calving was made up of four parts of barley meal and one part of coconut meal.

After calving the heifers were fed hay *ad lib.*, with a basic allowance of concentrates calculated at the rate of 0·5 per cent. of the body-weight, together with a 'production' concentrate ration of four pounds for every gallon of milk produced. This concentrate mixture consisted of: one part peanut meal, one part coconut meal, and two parts barley meal. The 'production' concentrate ration was adjusted weekly in accordance with individual milk production.

Cod-liver oil was mixed into the concentrates in sufficient quantity to prevent the occurrence of any vitamin A or D deficiencies.

The hay was lucerne hay and was fed 'chopped'. It and the barley meal were produced in New Zealand, while the coconut and peanut meals were produced in Fiji. These feeds were purchased in bulk in the respective countries, then each consignment was divided into half, one half being retained in the country of origin, and the other half shipped to the other country. This procedure made it possible to feed foods of approximately the same origin at each centre at the same time.

Management

The heifers at both centres were managed as similarly as possible, and management during the growth period was almost the same at both stations. They were all dehorned, ringed in the nose to prevent suckling of each other while idling in the yards, and drenched with phenothiazine at suitable intervals.

Mating. It was decided to follow New Zealand practice and mate the heifers at 15 months of age so that they would calve at approximately 2 years old. Twin Jersey bulls were used to serve the heifers. A set of

identical twin bulls was selected at Ruakura, and one was imported into Fiji in July 1950. The deadline for mating at both stations was set for 6 November 1951. The heifers at both stations were mated as they came on heat after this date. Data on the time of mating and the date of the three oestrus periods prior to mating are shown in Table 2. Five of the sixteen heifers had to be remated.

TABLE 2. *Data on Oestrus, and the Date of First and Repeat Matings*

Twin set	*Location*	*Twin no.*	*Date of three oestrus periods preceding mating*			*Date of mating*	*Date of repeat mating*
1	F.	17	4.9:5.9	24.9:5.9	18.10	7.11.50	
	N.Z.	18	19.8	9.9	18.10:20.10	25.12.50	
2	F.	23	17.9	1.10	2.11	23.11.50	
	N.Z.	24	25.9	10.10:12.10	15.11	17.12.50	7.5.51:28.5.51
3	F.	25	10.10	29.10	3.11	27.11.50	
	N.Z.	26	12.9	4.10	28.10	2.11.50	21.11.50
4	F.	29	25.9	15.10	4.11	24.11.50	
	N.Z.	30	15.9	7.10	27.10	19.11.50	9.12.50
5	F.	33	14.9	5.10	15.11	11.1.51	29.1.51
	N.Z.	34	27.8	24.9	3.10	18.12.50	
6	F.	39	26.9	16.10	3.11	23.11.50	
	N.Z.	40	9.9	30.9	18.10	10.11.50	
7	F.	45	13.8:14.8	1.9	23.9	8.11.50	
	N.Z.	46	11.9	4.10	24.10	17.11.50	9.12.50
8	F.	47	16.9	5.10	26.10:27.10	17.11.50	
	N.Z.	48	18.9	10.10	2.11	24.11.50	

Milking technique. Unfortunately milking technique was not exactly similar at both stations. It was planned to make every effort to obtain the maximum amount of the milk produced by the heifers, and milking and stripping at both stations was to be done by machine. The heifers were to be trained to the bail routine for one month prior to calving. Milking hours were fixed at 5 a.m. and 4 p.m. and back chains but no leg ropes were to be used. Udders were to be washed with tepid water in order to stimulate milk let-down and a teat cup was to be used. The machines at both stations were to be equipped with Ruakura sight glasses, and were to be set so that they would work at the same vacuum and at the same rate and ratio of pulsation. The technique of machine stripping that was to be used was as follows: the teat cups were to be gently pulled down for about ten pulsations while the udder was lightly massaged. All these techniques were used at Ruakura from the beginning, but owing to local difficulties a machine could not be installed at Sigatoka until 22 October 1951, so that seven of the eight heifers were milked and stripped by hand between 5 August and 22 October 1951. After 22 October 1951 the milking technique used at both stations was approximately the same.

This unfortunate circumstance undoubtedly introduced some error, and in addition it is very probable that milking technique was never as efficient at Sigatoka after machine milking was introduced as it was at Ruakura, as the labour at Sigatoka had to learn the new technique. The magnitude of the error cannot be ascertained, but this fact must be taken into consideration when comparing production records from the heifers at the two stations.

Drying-off technique. It was decided to 'dry off' the heifers at 309 days after calving (the calving day being included) or whenever the production of an individual heifer had fallen below a total of 8 lb. of milk per day or 2 lb. of butterfat per week for four consecutive weeks.

Experimental Recording

Weekly recording of body-weight and body measurements was carried out during the lactation period of the heifers as they had been during the growth period. Some details of these data are given in the first paper [1].

Recording of feed and water intake also continued throughout the first lactation period. Detailed oestrus-period records were kept, as were health records.

In addition, milk was weighed daily at both stations. At Ruakura the percentage of butterfat in the milk was determined daily, while at Sigatoka it was determined on two consecutive days of the week. At both stations the Gerber method of butterfat determination as prescribed in British Standards [3] was used. At Ruakura the percentage of total solids in the milk was determined on two consecutive days each week and at Sigatoka on one day. Total solids was determined at both stations by the method recommended by the Society of Public Analysts [4].

Weekly recordings were also made of rectal temperatures and respiration rates. The recordings were made on the same day and the same methods were used at both stations. A clinical thermometer was used to measure rectal temperature and recordings were made twice daily at 11 a.m. and 3 p.m. on three consecutive days, when the animals were in a resting state. A mean of the six recordings was used as a measure of the animal's daytime rectal temperature. Respiration rates were measured by timing the animal's flank movements with a stop-watch. Six recordings were taken at the same time as the rectal temperatures and a mean daytime respiration rate thus obtained.

Results

Health

Unfortunately the health of many of the twins during their lactation period was not good. In the first set, No. 17 in Fiji developed mastitis in the right-hind teat during June 1952 but recovered after treatment, while No. 18 in New Zealand developed an eczema some seven weeks after calving and had to be dried off. In the second set, No. 24 in New Zealand developed an undiagnosed condition and had to be dried off after a short lactation of ninety-four days. In the third set, No. 25 in Fiji calved prematurely and the calf was stillborn but the heifer recovered rapidly, and No. 26 in New Zealand developed ketosis after calving but recovered. In the fifth set, No. 33 in Fiji developed mastitis in the left-hind teat three days after calving. After treatment it recovered but the condition developed again two months later, when after a second treatment the animal was finally cured. In the seventh set, No. 46 in New Zealand lost condition after calving, but the cause was not diagnosed. In the eighth set, No. 48 in New Zealand was found to be in poor condi-

tion after calving and probably suffered from mild ketosis, but it recovered.

Thus only two of the eight sets of twins provided production data uncomplicated by any uncontrolled disease factors.

Production

The dates of calving and drying-off and the length of the experimental lactation period are shown in Table 3. Three animals in Fiji, Nos. 23, 45, and 47, were not actually dried off on the 305th day of the lactation

TABLE 3. *Dates of Calving and Drying-off and Length of Lactation*

Twin set	*Location*	*Twin no.*	*Date of calving*	*Date dried off*	*Length of lactation (days)*
1	F.	17	5.8.51	12.6.52	305
	N.Z.	18	6.10.51	23.11.51	48
2	F.	23	26.8.51	29.6.52	305
	N.Z.	24	16.2.52	21.5.52	91
3	F.	25	13.8.51	1.3.52	201
	N.Z.	26	2.9.51	5.7.52	305
4	F.	29	10.9.51	19.4.52	218
	N.Z.	30	14.9.51	20.7.52	305
5	F.	33	13.11.51	4.8.52	258
	N.Z.	34	29.9.51	3.8.52	305
6	F.	39	27.8.51	11.3.52	194
	N.Z.	40	6.8.51	9.6.52	305
7	F.	45	21.8.51	24.6.52	305
	N.Z.	46	20.9.51	28.7.52	305
8	F.	47	16.9.51	20.7.52	305
	N.Z.	48	11.9.51	15.7.52	305

period, but were dried off on 28 August 1952. This was done because these animals would otherwise have had an extremely long dry period before their second calvings, and the decision had no effect on the experiment in any way. Hancock [5] states that where there are wide discrepancies in calving time within a monozygotic twin set this may cause production differences that cannot be separated from the experimental treatment. He suggests that in order to ensure reasonable precision in experimental results a set of twins with a greater than forty-days' interval between calving dates should be discarded from an experiment. It is not certain whether these criteria can be applied in this experiment as the same feed was provided throughout the period, but very wide within-set discrepancies in calving time would certainly reduce the value of any comparisons. The intervals between calvings in the eight sets, in days, were: set 1, 62; set 2, 174; set 3, 20; set 4, 4; set 5, 45; set 6, 21; set 7, 30; and set 8, 5. Thus in three sets the discrepancy in calving dates was more than 40 days.

The production records of the first two sets of twins have been omitted from the results, as heifers Nos. 18 and 24 in New Zealand became ill and had to be dried-off prematurely. This reduces the number of twin comparisons to six, inclusive of set No. 5 where the calving

interval was rather long. In addition only two of the six sets provided data entirely uncomplicated by any uncontrollable disease factors. These facts have reduced the value of any complex analysis of the production data, and it is therefore presented in a relatively simple form.

Details of the total milk, 4-per-cent.-fat-corrected milk, butterfat, and solids-not-fat production of the six sets of twins are presented in Table 4,

TABLE 4. *Milk, F.C.M., Butterfat, and Solids-not-fat Production (lb.)*

Twin set	*Location*	*Twin no.*	*Total milk*	*Diff. (N.Z.–F.)*	*F.C.M.*	*Production diff. (N.Z.–F.)*	*Butterfat*	*Diff. (N.Z.–F.)*	*S.N.F.*	*Diff. (N.Z.–F.)*
3	F.	25	2,258		2,201		86·5		172·7	
	N.Z.	26	4,371	2,113	4,726	2,525	198·5	112·0	366·2	193·5
4	F.	29	2,841		2,744		107·2		237·4	
	N.Z.	30	5,491	2,650	5,739	2,995	236·2	129·0	461·2	223·8
5	F.	33	2,820		3,260		142·1		242·0	
	N.Z.	34	5,466	2,646	6,197	2,937	267·4	125·3	464·4	222·4
6	F.	39	2,646		3,110		136·8		242·6	
	N.Z.	40	5,249	2,603	6,825	3,715	315·0	178·2	457·2	214·6
7	F.	45	5,560		6,409		279·0		493·9	
	N.Z.	46	5,442	−118	6,972	563	319·7	40·7	468·0	−25·9
8	F.	47	4,982		5,776		252·2		433·2	
	N.Z.	48	4,383	−599	5,214	−562	230·7	−21·5	370·1	−63·1
Average:										
	F.		3,517·8		3,916·7		167·3		363·3	
	N.Z.		5,067·0	1,549·2	5,861·2	1,944·5*	261·3	94·0*	431·2	67·9
				n.s.						n.s.

* Significant at P = 0·05. n.s. = not significant.

while details of the average butterfat and solids-not-fat percentages are shown in Table 5. Average milk production was considerably higher in New Zealand than in Fiji, though the difference was not quite significant at the P = 0·05 level. Of special interest is the fact that all the Fiji twins did not react in the same way to the stress of a tropical climate. Within four sets the New Zealand twins produced almost twice as much milk as their co-twins in Fiji, whereas in the other two sets the twins in Fiji produced a little more than their co-twins in New Zealand. An examination of the lactation curves, in Fig. 2, shows that the twins in Fiji, with the possible exception of No. 47, exhibited abnormal lactation curves. Production did not rise to so high a peak as normal, and then usually fell off more rapidly. Four out of six of the twins showed a lack of persistency. No. 46 in New Zealand did not reach a normal peak, as production fell off rapidly early in the lactation but recovered later. This was due to an undiagnosed condition, as mentioned above, and it is possible that if this animal had not fallen ill early in the lactation, its production would have been above that of its co-twin in Fiji. If allowances are made for these complications it would still appear from the data that Nos. 45 and 47 in Fiji were in some way better adapted for production in a tropical climate than the other twins in Fiji and at least showed persistency in production.

When the milk-production records were corrected for fat percentage the average 4-per-cent.-fat-corrected milk production of the Fiji twins was significantly (at P = 0·05) lower than that of their co-twins in New

Zealand, since the tropical climatic environment appeared to affect fat more than milk production.

It will be seen from Table 4 that differences in butterfat production were significant (at $P = 0.05$), only No. 47 in Fiji producing more butterfat than its co-twin in New Zealand. On the average the New

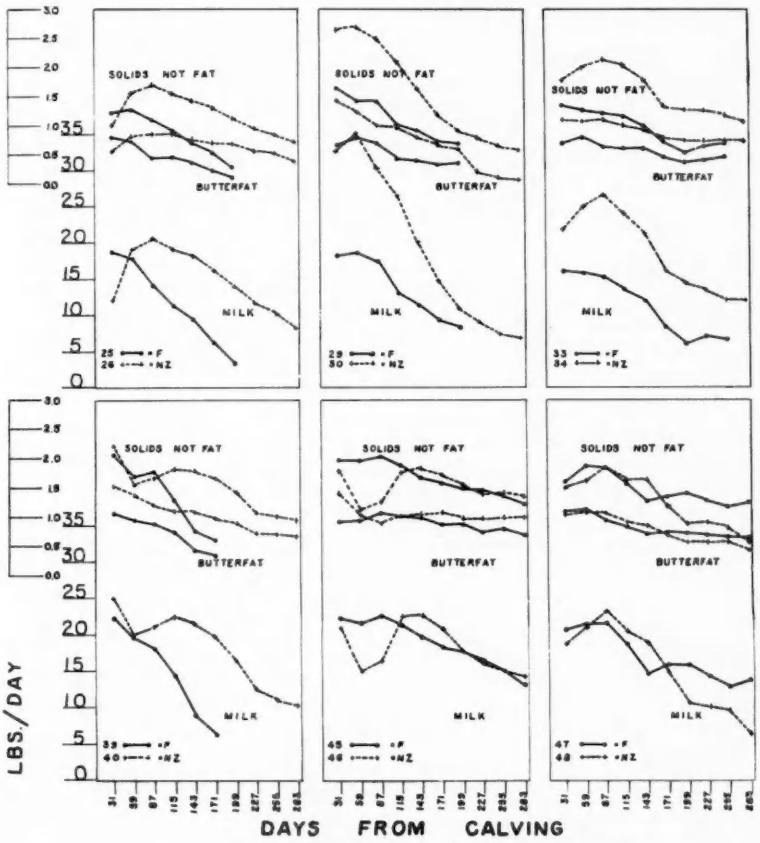

FIG. 2. Milk, butterfat, and solids-not-fat production.

Zealand twins produced 56 per cent. more butterfat and 44 per cent. more milk than their co-twins in Fiji. It will, however, be noted that, as in the case of milk production, there were large individual variations in the effect of climatic stress on the butterfat production of the Fiji twins.

There were not such large differences in solids-not-fat as in milk and butterfat production, the New Zealand twins only producing 19 per cent. more solids-not-fat than the Fiji twins, the average difference

not being statistically significant. This was due to the fact that there was virtually no difference in the percentage of solids-not-fat in the milk of the Fiji and New Zealand twins (Table 5).

TABLE 5. *Butterfat and Solids-not-fat Percentages*

Twin set	*Location*	*Twin no.*	*Butterfat %*	*Diff. (N.Z.–F.)*	*Solids-not-fat %*	*Diff. (N.Z.–F.)*
3	F.	25	3·83		7·65	
	N.Z.	26	4·54	0·71	8·32	0·67
4	F.	29	3·77		8·17	
	N.Z.	30	4·30	0·53	8·40	0·23
5	F.	33	5·04		8·58	
	N.Z.	34	4·89	−0·15	8·50	−0·08
6	F.	39	4·00		9·17	
	N.Z.	40	6·00	2·00	8·71	−0·46
7	F.	45	5·02		8·88	
	N.Z.	46	5·87	0·85	8·60	−0·28
8	F.	47	5·06		8·70	
	N.Z.	48	5·26	0·20	8·44	−0·26
Average:						
	F.		4·755		8·631	
	N.Z.		5·155	0·400	8·509	−0·122
				n.s.		n.s.

n.s. = not significant.

Details of the variations in the monthly butterfat and solids-not-fat percentages are shown in Fig. 3. It will be seen that the butterfat percentage of the milk of the Fiji twins did not in general rise towards the end of lactation as it normally does.

Feed Intake

Table 6 shows that the average hay intake of the twins in Fiji was significantly lower (at $P = 0{\cdot}01$) than that of their co-twins in New Zealand, whereas the average intake of concentrates was higher, though the difference was not quite statistically significant. The twins were allowed as much hay as they would consume while their concentrate intake was rationed, partly by body-weight and partly by production. It is obvious that the twins in Fiji ate all the concentrates that were available but did not eat the hay so readily. It is probable that when the appetite is lowered animals select the most palatable feeds if they have a choice and it is perhaps significant that the crude-fibre content of the hay was 32 per cent. while that of the concentrate mix was 10·5 per cent. The two twins in Fiji with the highest production, Nos. 45 and 47, did not differ from the other Fiji twins in their hay intake, but their concentrate intake per pound of milk produced was more similar to their New Zealand co-twins than to the other twins in Fiji.

The total starch equivalent of the ration was calculated using the digestibility coefficients for the various feeds given by Morrison [6].

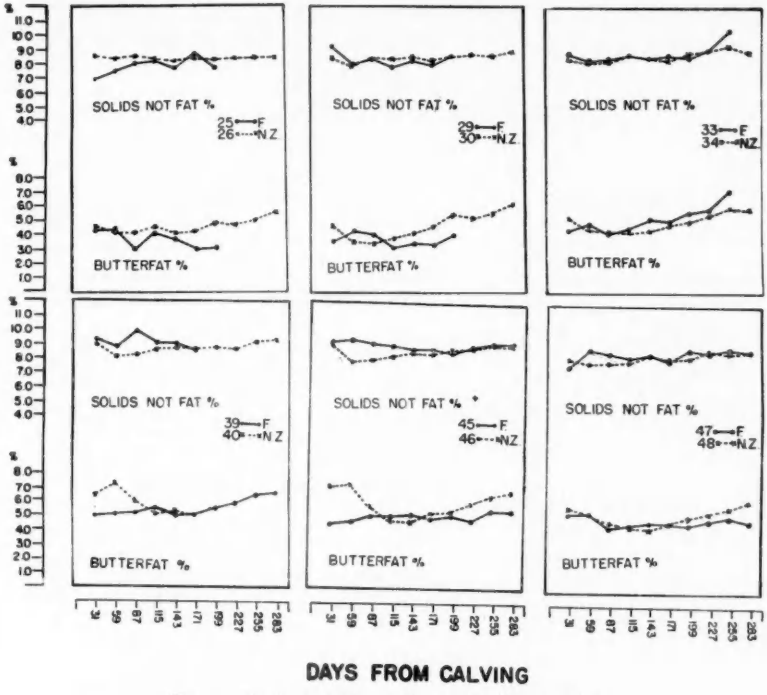

FIG. 3. Percentage butterfat and solids-not-fat.

TABLE 6. *Hay and Concentrate Intake per lb. of Milk produced, and Total Starch-equivalent Intake per lb. of Milk and F.C.M. produced*

Twin set	*Location*	*Twin no.*	*Feed intake per lb. milk*		*S.E. intake per lb. milk*	
			Hay	*Concentrate*	*Uncorrected*	*F.C.M.*
3	F.	25	0·519	0·831	0·850	0·872
	N.Z.	26	0·907	0·483	0·818	0·757
4	F.	29	0·533	0·827	0·856	0·885
	N.Z.	30	0·875	0·548	0·846	0·809
5	F.	33	0·747	1·196	1·224	1·059
	N.Z.	34	0·776	0·498	0·758	0·669
6	F.	39	0·398	0·741	0·723	0·615
	N.Z.	40	0·811	0·440	0·737	0·567
7	F.	45	0·587	0·607	0·732	0·635
	N.Z.	46	0·784	0·594	0·829	0·647
8	F.	47	0·453	0·688	0·716	0·618
	N.Z.	48	1·011	0·742	1·053	0·885
Average:						
	F.		0·540	0·815	0·850	0·781
	N.Z.		0·861†	0·551 n.s.	0·840 n.s.	0·722 n.s.

† = Significant at P = 0·01. n.s. = not significant.

Table 6 shows that the differences in starch-equivalent intake per pound of uncorrected and 4-per-cent.-fat-corrected milk were not statistically significant and were quite similar for the twins in both climatic environments. Thus it would appear that the average efficiency of production was about the same in Fiji and New Zealand; however, it will be seen that the poor producers in Fiji were less efficient and the better producers slightly more efficient than their New Zealand co-twins. As this measure of the efficiency of milk production could be confounded by the fact that the heifers were still growing during the first lactation, some details of live weight before and after lactation are shown in Table 7. These

TABLE 7. *Live weight before Calving (on 25.6.51 at the end of period 5) and at the End of the Lactation (21.7.52)*

Twin set	*Location*	*Twin no.*	*Live weight (lb.)*	
			25.6.51	*21.7.52*
3	F.	25	946	1,095
	N.Z.	26	968	1,019
4	F.	29	812	940
	N.Z.	30	882	1,049
5	F.	33	711	797
	N.Z.	34	746	811
6	F.	39	716	757
	N.Z.	40	837	879
7	F.	45	835	830
	N.Z.	46	997	923
8	F.	47	813	828
	N.Z.	48	883	938
Average:				
	F.		789	875
	N.Z.		873	937

data do not suggest that Nos. 45 and 47 in Fiji produced as well as their co-twins in New Zealand by utilizing body reserves. Nos. 45 and 46 both lost some weight during lactation and Nos. 47 and 48 both gained weight.

Water Intake

The average 24-hour water consumption throughout the lactation period, together with the water consumption per pound of milk produced, is shown in Table 8. Water consumption of the Fiji twins during lactation was much higher than that of their New Zealand co-twins, as it also had been during the growth period [1]. Differences in 24-hour consumption were significant (at $P = 0.05$), while differences in the amount of water consumed per pound of milk produced were highly significant (at $P = 0.01$). There were also significant positive correlations (at $P = 0.01$) between the mean daily body temperature ($r = 0.820$) and (at $P = 0.05$) between the mean daily respiration rate ($r = 0.581$), and the mean daily water consumption during the lactation.

TABLE 8. *Average 24-hour Water Consumption, Water Consumption per lb. of Milk produced and Within-set Differences (pints)*

Twin set	*Location*	*Twin no.*	*24-hour water consumption*	*Diff. (F.–N.Z.)*	*Water consumption per lb. milk*	*Diff. (F.–N.Z.)*
3	F.	25	108·0	28·4	9·61	4·06
	N.Z.	26	79·6		5·55	
4	F.	29	103·9	34·8	7·98	3·94
	N.Z.	30	69·1		3·84	
5	F.	33	85·4	17·1	7·81	4·00
	N.Z.	34	68·3		3·81	
6	F.	39	82·4	10·7	6·04	1·88
	N.Z.	40	71·7		4·16	
7	F.	45	167·4	84·0	9·18	4·67
	N.Z.	46	80·4		4·51	
8	F.	47	109·8	32·9	6·72	1·37
	N.Z.	48	76·9		5·35	
Average:						
	F.		109·5	35·2*	7·89	3·35†
	N.Z.		74·3		4·54	

* Significant at P = 0·05. † Significant at P = 0·01.

Rectal temperature and respiration rate

Data on average daily temperature and respiration rate of the six sets of twins are shown in Table 9. The twins in New Zealand maintained normal rectal temperature [7] and respiration rate, but those of their co-twins in Fiji were abnormal. There was no significant correlation between milk production per day and average daily rectal temperature or respiration rate.

TABLE 9. *Average Day Rectal Temperature and Respiration Rate*

Twin set	*Location*	*Twin no.*	*Av. day rectal temp. °F.*	*Av. day resp. rate (per min.)*
3	F.	25	102·08	88·8
	N.Z.	26	101·14	29·6
4	F.	29	101·71	87·8
	N.Z.	30	101·12	37·8
5	F.	33	102·21	106·1
	N.Z.	34	100·89	31·3
6	F.	39	102·32	97·9
	N.Z.	40	101·43	33·7
7	F.	45	103·03	90·9
	N.Z.	46	101·43	28·2
8	F.	47	102·24	81·1
	N.Z.	48	101·05	21·0
Average:				
	F.		102·27	92·0
	N.Z.		101·18	30·3

Discussion

It was unfortunate that the number of twin comparisons had to be reduced from eight to six and that all the twins did not calve down at the same time. These are of course the normal hazards of twin experimentation, as ill health cannot be entirely avoided even with the best management, and it was not possible to have all the twins calve down together because (*a*) they were different ages although born in the same season; (*b*) oestrus occurs at random over approximately 21-day intervals even within a twin set; and (*c*) a 100 per cent. conception rate cannot be assured.

Many field studies on the effect of environmental temperature on milk, butterfat, and solids-not-fat production have been made in the past. The literature has been reviewed by Findlay [8] and Hancock [9]. Most of the work indicates that milk, butterfat, and solids-not-fat production are depressed by high summer temperatures but, as remarked by Hancock, it is difficult to disentangle direct temperature effects from those caused by changes in feeding. This experiment appears to be the first field study in which a direct comparison of the effect of tropical and temperate climatic environments has been made, uncomplicated by differences in management and feeding.

More recent climatic-chamber studies on the effect of temperature on dairy cattle have also been reviewed by Findlay [8] and Hancock [9]; the results can be summarized as follows. With increasing ambient air temperature appetite is depressed, food intake lowered, and heat production reduced. In a given fixed environment a decrease in heat production can be brought about only by a decrease in productivity, so that milk and butterfat production decline. Whether the high temperature directly affects the appetite, thus leading to a decrease in feed intake and a consequent drop in productivity and heat production, or whether the necessity to decrease heat production leads to a decline in production that automatically decreases appetite and hence feed intake, is not known. The climatic-chamber studies showed that, with Jersey cattle, milk production slowly decreased with rising air temperature starting from 50° to 60° F. until somewhere between 70° and 80° F. a critical point was reached and production declined more rapidly. Fat percentage declined slowly until the air temperature reached 85° F. and then it increased. The combined effect of the fall in milk production and a decline in fat percentage at temperatures up to 85° F. caused a drop in fat production, and although fat percentage may rise at temperatures above 85° F. the decline in milk production was then so steep that total fat production probably declined still further. Air temperatures in Fiji are normally above 70° F., the average minimum temperature during the major part of the lactation period from January to July 1952 being 70° F., so that it would be expected that the productivity of the Fiji twins would be less than that of their co-twins in New Zealand. There was in fact a large average difference in the production of both milk and butterfat. What is more interesting is that the twins in Fiji did not respond in a uniform manner to the stress of a tropical climate. Two

of the twins in Fiji, Nos. 45 and 47, produced at almost the same level as their co-twins in New Zealand, while the level of production of the other four twins was well below that of their co-twins. This suggests that there are profound differences in the reaction of temperate-type dairy cattle of the same breed to a tropical climate. This conclusion is reinforced by information obtained from the study of the 'heat tolerance' of stock in Fiji [10], where it has been found that the 'heat tolerance' of individual animals within a breed may vary considerably and that although the mean heat-tolerance coefficient of tropical-type and cross-bred cattle is generally above that of temperate-type cattle, individual temperate-type cattle possess a degree of 'heat tolerance' as high as that shown by tropical-type cattle. This raises the interesting question as to whether suitable strains of temperate-type cattle can be selected for use in the tropics. These results also raise doubts as to the validity of some conclusions that have been drawn from climate-chamber experiments where a small number of animals are tested, on the effects of heat stress on large cattle populations. Quite different conclusions on the effect of moderate heat stress on Jersey cattle would have been reached if Nos. 45 and 47 had been used in a climate-chamber experiment, rather than Nos. 25 and 29.

It is interesting that the lactation curves of the twins in Fiji were abnormal in that they did not exhibit the usual high peak of production and lacked persistency. Lack of a high peak of production could be explained on the assumption that if production had risen to its normal peak, heat production would have been so excessive that the animal could not have dealt with the situation and there would have been a breakdown in the heat regulatory mechanism. The phenomena of a lack of persistence at a lower level of production is more difficult to explain.

Although the average solids-not-fat production of the Fiji twins was markedly lower than that of their co-twins in New Zealand, this was due to a lower total production of milk rather than to a difference in the percentage of solids-not-fat; in fact the solids-not-fat percentage of the milk of the Fiji twins was slightly higher than that of their co-twins. At Missouri, Cobble and Herman [11] found that solids-not-fat percentage declined with increasing environmental temperature above 85° to 90° F. As mean daily temperatures in Fiji are usually below 85° F. it is probable that the air temperature in Fiji was not high enough for a sufficiently long period to affect the solids-not-fat percentage.

As stated above, the results of climatic-chamber experiments, particularly at Missouri, show that with increasing air temperature appetite is depressed and food intake declines. It should be noted that although intake was lower in the Fiji twins, they lowered their intake of hay rather than that of concentrates. It is interesting to speculate whether it would be possible to improve the productivity of temperate-type cattle in a tropical climatic environment by feeding them a higher proportion of concentrates than is normal in temperate countries. If the type of feed that the animal consumes is of importance, then heat production in digestion is possibly of greater importance than it was thought to be. The

data on total starch-equivalent intake and starch equivalent utilized per pound of milk produced (Table 6) for Fiji twins Nos. 45 and 47 suggest that, if a temperate-type milking animal is 'heat tolerant' in the sense that it is able to maintain its productivity in a tropical environment, it should be able to produce milk more efficiently in a tropical than in a temperate climate environment, efficiency in this case being measured by the ratio of starch-equivalent intake to milk production.

Leitch and Thomson [12] reviewed the subject of water intake of cattle in 1944 and concluded that it varies with the type of feed, the method of feeding, the production level of the animal, the climate and the individuality of the animal, and that other things being equal water intake rises with a rise in ambient air temperature. Morrison [6] states that the lactating cow consumes 3·4 to 5·5 lb. of water for every pound of milk produced, presumably in a temperate-climatic environment. It will be noted from Table 8 that the twins in New Zealand did consume approximately this amount of water but that their co-twins in Fiji utilized almost twice as much.

Recent climatic-chamber work by Thompson *et al.* [13] and Ragsdale *et al.* [14] at Missouri, using Jersey, Holstein, and Brahman cattle, has shown that although water consumption usually increases as the ambient air temperature rises from 50° to 105° F. there is considerable individuality in the response of the animal, and some Jersey and Holstein cows actually decrease their water consumption. They suggest that in general the greater the water consumption of the animal the less the rise in rectal temperature and depression in milk production and feed consumption. These conclusions do not agree with the results obtained in this experiment, as it was found that there was a highly significant positive correlation between rectal temperature and water consumption.

Field studies that have been conducted recently also showed that water consumption rose with an increase in ambient air temperature, but as these studies have been carried out using tropical-type cattle the results are not strictly comparable with the results from the present experiment. Mullick *et al.* [15] at Izatnagur in northern India, using six Kumani hill steers, showed that water intake was highest in the summer (24·0–32·2 pints per 24-hour period) and lowest in the winter (15·1–20·1 pints per 24-hour period).

It is likely that cattle can utilize increased water consumption to reduce their heat load in two ways. First, the ingested water will usually be at a lower temperature than the body temperature of the animal, so that if the animal ingests a large volume and then heats it to body temperature, finally secreting it as urine, it has a useful mechanism for disposing of surplus heat. Secondly, as the rate of respiratory and surface vaporization increases with increasing ambient temperature [16] the animal has to ingest more water to keep this mechanism working. Failure to increase water consumption will eventually lead to a decrease in heat loss by this mechanism. Thus an animal that is able to increase its water consumption with rising ambient air temperatures has a definite advantage over other animals in the same environment that do not have this capacity. The data in Table 8 suggest that No. 45 in Fiji had this inherent capacity,

since its water intake was far higher than that of its co-twin in New Zealand or of the other twins in Fiji, while its milk production was almost equal to that of its co-twin in New Zealand despite the fact that its rectal temperature, though not its respiration rate, was far higher than that of any other twin in Fiji. On the other hand, the water consumption of No. 47 in Fiji, the other animal whose production was as high as its co-twin in New Zealand, was not nearly so high as that of twin No. 45. Thus the two animals that appeared to be 'heat tolerant', since they were able to produce at approximately the same level in a tropical climate as their co-twins in a temperate climate, differed markedly in their level of water consumption. This suggests that the relationship between heat tolerance and the ability to increase water consumption is very complex.

It may be concluded that it is particularly necessary to provide adequate supplies of fresh drinking water to temperate-type milking cows in a tropical climatic environment, and that estimates of need for water should not be based on temperate-zone standards. It is also probable that the increased water consumption of some temperate-type dairy cows in a tropical climatic environment assists them in maintaining production by helping them in various ways to reduce their 'heat load'.

Findlay [8] has recently reviewed the literature on the reaction of temperate-type cattle to high ambient air temperature both in field and climate-chamber studies. Rectal temperature and respiration rate rise with an increase in ambient air temperature, and the rise is most pronounced when the ambient air temperature is above 85° F. Average maximum temperature was 85·5° F. in Fiji during the period January to July 1952 (Table 1), i.e. during a major part of the lactation period, and the twins in Fiji reacted in the same way as did animals in the experiments that Findlay reviewed, their average daily rectal temperature and respiration rate being considerably above that of their co-twins in New Zealand.

The magnitude of the rise in rectal temperature has been used as a measure of the 'heat tolerance' of cattle by many workers [8], but the results of this experiment suggest that considerable caution should be exercised in applying this test to some lactating temperate-type cattle, as there was no correlation between the average daily rectal temperature or respiration rate of the twins and their daily level of milk production. In fact No. 45, the twin with the highest average daily production in Fiji, also had the highest average daily rectal temperature (103·03° F.). If 'heat tolerance' is to be defined as the ability of the animal to maintain normal physiological function under heat stress, then a 'heat tolerant' animal would be one that most nearly maintains normal production regardless of the rectal temperature or respiration rate. In this connexion Branton *et al.* [17], working in Louisiana, have shown that if animals with the lowest body temperature are to be considered the most 'heat tolerant', then their data indicate that there is a sizeable negative genetic relationship between 'heat tolerance' and milk production.

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INVESTIGATIONS INTO PROBLEMS INVOLVED IN THE PRODUCTION OF BEEF FROM DAIRY-BRED STEERS

A. J. BROOKES AND J. O. LATHAM

(*School of Agriculture, University of Cambridge*)

WITH PLATES 7 AND 8

Summary

The dependence of the home beef industry upon the dairy industry for the supply of suitable calves for rearing for beef is discussed.

Reference is made to the beef-production experiments on the Cambridge University Farm, in which the value of a good start in life for the calf destined for beef has been demonstrated and measured.

A survey involving following large numbers of dairy-bred steers from commercial farms to the slaughter-house to assess the type of carcass produced under various environmental conditions has recently been started. Most attention is being devoted to Friesian and Dairy Shorthorn steers and the steers obtained by crossing cows of these two breeds with beef bulls.

Carcasses obtained from cattle in this survey are measured and compared with Argentine chilled beef. A smaller number of carcasses are examined in greater detail by jointing, to obtain information on the proportions of the various parts and the variation which occurs in practice.

Plans for weighing cattle in this survey at various ages to assess growth-rates and economy of food conversion at various stages of life are mentioned.

A small-scale investigation into the quality of meat produced by immature and 2-year-old Friesian and Angus × Friesian cattle is described and the carcasses are compared with that of a mature Friesian bullock and also with chilled Argentine beef. The carcasses were very similar in many respects, but the mature Friesian bullock had a good deal more trimmable fat in the hindquarters. In all cases the proportions of the quarter represented by various joints were remarkably similar. This investigation is to be repeated.

The husbandry angle of producing light-weight fat cattle from dairy-bred steers is briefly discussed and an approximate economic assessment made. The profitability to the farmer of producing young light-weight cattle (2 years old) is compared with that of older mature cattle ($2\frac{1}{2}$–3 years old).

An inquiry into cheaper wintering systems possible for beef cattle has recently been started.

DURING the past twenty years very considerable changes have taken place within the national cattle herd, affecting both the composition of the national dairy herd and also the proportion of various types of cattle being used for home beef production. Before the 1939–45 war a considerable proportion of the national dairy herd consisted of cows of dual-purpose breeds. An indication of the relative importance of various breeds is evident from a study of the number of bull licences granted by the Ministry of Agriculture. For example, in the year 1936–7, 65 per cent. of the bulls licensed in England and Wales were Shorthorn (including Beef Shorthorns, of which the number would be very small) and 6·6 per cent. were Friesians. Ayrshire and Channel Island bulls together accounted for 7·8 per cent. of the total. By the year 1949–50, Friesian

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bulls accounted for 28·6 per cent. of those licensed and the proportion of Shorthorns had dropped to 28·3 per cent. The percentage of Ayrshire and Channel Island bulls had also increased. This swing towards dairy breeds in the national dairy herd has continued. In 1955 the Milk Marketing Board estimated from a questionnaire sent to all wholesale milk producers that 66·7 per cent. of the animals in milking herds were of dairy breeds (Ayrshire, Friesian, or Channel Island) and Friesians accounted for 40·5 per cent. of the total, whereas dual-purpose breeds accounted for 28·9 per cent. and of this group Dairy Shorthorns formed 25·3 per cent. [1, 1955–6].

Within the same period of time changes have taken place in the beef industry; one of these is the greater use which has been made of calves from milk-producing herds for rearing as beef. In spite of the change of emphasis within the national dairy herd from mainly dual-purpose cattle to more cows of dairy breeds this use of dairy-bred calves for beef has continued. In a small, densely populated country such as this there can never be a sufficient number of store cattle of pure beef breeding to meet the requirements of the rearers and feeders, and some of the raw material for beef production must therefore come as a by-product of the milking industry if home beef production is to be on a considerable scale. Not all calves born in milk-producing herds are suitable for rearing as beef, and for obvious reasons calves from the extremely fine dairy type of cow must be discounted. Fortunately, however, there are in this country a very large number of cows which, though they are profitable milk producers, have the frame and conformation which make them suitable for producing steers for rearing as beef cattle. There can be little doubt that in future a flourishing beef industry in this country can only obtain enough calves for rearing through its dependence on the dairy industry. Such a concept, though widely accepted today, did not by any means receive general support twenty years ago.

It is extremely difficult to estimate what proportion of prime home-killed beef (steers and maiden heifers) is derived from cattle bred in milking herds (including pure-bred dairy or dual-purpose cattle and also cattle out of such cows and sired by a beef bull). In a very detailed statistical and economic survey of the cattle industry of Great Britain between 1939 and 1945, Marley [2] estimated the approximate number of calves being reared for beef but gave no indication of how these were bred. Engledow and Hudson (unpublished data) attempted to follow up this work and hoped to trace the origin of replacement stock for dairy herds, beef herds, and beef fattening. They made a study of the quarterly agricultural returns obtained by the Ministry of Agriculture, and also of various sources of information on slaughterings, wastages, &c. While they found precision impossible to obtain because of the many assumptions which had to be made for their calculations, the general trend was clear. This investigation showed a very considerable dependence of the beef industry upon the dairy industry for the supply of store cattle for finishing as prime beef.

Calves from the dairy industry available for beef-rearing include pure-bred steer calves from such breeds as Dairy Shorthorn, Friesian,

Red Poll, South Devon, &c., and a few surplus heifers not required for replacements, and also crossbred cattle sired by beef bulls out of cows of these and other milk-producing breeds. As a result of the spread of attestation in Great Britain, and the improvement in length of herd life of cows of the national herd resulting from greater control of disease over the past decade, fewer cows in milking herds need to be bred pure to obtain sufficient replacements to make the herd self-supporting. In many herds it is sufficient to mate the best two-thirds of the cows to breed the herd replacements, and the remaining one-third is available for crossing with a beef bull to breed crossbred calves for beef production. Such a practice is greatly facilitated through artificial insemination, as any dairy farmer can have some or all of his cows, no matter how few, inseminated to a beef breed of bull. A certain amount of crossbreeding for beef purposes is therefore possible in any herd without keeping a beef bull on the farm. Many farmers are making use of this service, for in 1953–4 18·8 per cent. of over 1¼ million cows in England and Wales were inseminated with beef semen [1, 1954]. Preliminary reports suggest that more cows may be mated to beef bulls in future. However, there will still be a considerable number of steer calves of pure dairy or pure dual-purpose breeding available for rearing, and experience suggests that many of them are well worth rearing for beef and should indeed be reared for this purpose rather than slaughtered for manufacturing.

Beef-production Experiments at Cambridge

A great deal of experimental evidence is now available from the Cambridge beef-production experiments [3, 4] to support the view long appreciated by the best stock rearers that the early life of an animal destined for beef should be spent on a generous level of feeding. In those experiments Hereford, Dairy Shorthorn, and Friesian steer calves have been divided into two groups and reared on either a high or a moderate level of feeding for the first eight months. After eight months half of each group was left on the same level of feeding, and the other half changed to a higher or lower level of feeding during the subsequent winter periods. This gives four feeding treatments, represented by the now familiar terms, high-high, high-moderate, moderate-high, and moderate-moderate. These experiments were first concerned with spring-born calves and were carried out continuously over a period of ten years. The results were overwhelmingly in favour of giving the calf a good start. It has been found that cattle which are well reared initially are subsequently able to deal more efficiently with bulky, less digestible, and usually cheaper foods than are calves which are not so well reared.

Highly satisfactory carcasses of beef acceptable to the trade have been obtained during the course of those experiments from cattle which have been done well as calves. This applied to all three breeds. Satisfactory bodies of beef were obtained from Friesian calves out of the modern type of Friesian cows provided these calves were reared well initially. If the calves were not reared well enough in the early stages, the cattle were old and heavy before they would fatten off grass (i.e. on the moderate-moderate treatment the steers were not sold until they were

3½ years old). On this treatment many Friesian steers were 14 cwt. or over before they achieved a satisfactory level of finish and would dress out at 56 per cent.

In the autumn of 1953 another series of experiments was started at Cambridge dealing with autumn-born calves to investigate further the effects of levels of rearing in beef production. In many milking herds, a considerable proportion of the calves are autumn-born and it seemed desirable to investigate some of the problems involved in rearing suitable calves for beef. There are four feeding treatments in that experiment: two multiple-suckling treatments, one of six months' and the other of three months' duration, and two pail-feeding treatments, one involving the use of unrestricted concentrates in addition to milk and the other a severely limited amount of concentrates with the same amount of milk. Although those experiments are far from complete and must be continued for a few more years in order to deal with sufficiently large numbers of animals, present indications are that a good start is just as important for the autumn-born calf as for its spring-born counterpart.

With autumn-born calves the aim should be to make the maximum use of grass in the second stage of the animal's life (i.e. between 6 and 12 months of age) and so to cheapen this stage of the rearing. How should calves be reared in order that they may obtain a good growth-rate on grass without resort to additional hand feeding? Although further work is necessary to give a complete answer to this question, the experiments have gone far enough to support the experience of many rearers that a high level of feeding in early life is necessary. Calves born early in the autumn will be strong enough to spend their first summer on grass alone if, and only if, they have been well reared. In most areas by the beginning of May the weather should be suitable for them to go out for a short period each day, gradually extending the time. After about a fortnight of this, if the nights are warm enough, the calves may be turned away to grass and fed no more concentrates and hay. Thus, they may get three to four months cheap keep, a valuable contribution towards the solution of the problem of reducing the cost of beef production at all stages from calfhood to the finished fat beast. At present only one year's rear of autumn-born calves on those experiments has been slaughtered and further publication on this work must await the accumulation of more detailed information.

Survey of Beef Production from Commercial Dairy Herds

In those rearing experiments the number of cattle dealt with in any one year must of necessity be small, the number being severely limited by the winter accommodation, winter feed, and summer grazing available on the University Farm over and above that required for the normal herds and flocks of the farm. Each year twenty-four calves have been reared on the beef-production experiments, comprising eight of each of the three breeds. Consequently, many years of work are required in order to accumulate data from a sufficient number of representatives of each breed. However, in the course of time much precise and valuable information has been and still is being collected. To supplement this,

further research of a survey character has been undertaken to discover how far the general run of beef carcasses produced in farm practice compare with what consumers require and to what extent various breeds and cross-breeds vary in carcass quality. It is completely impossible to make an accurate experiment on the latter point largely because of the wide individual variation within one breed; even 50 animals of one breed may be insufficient to represent that breed adequately. However, much valuable data may be obtained by following animals from commercial farms through to slaughter, making observations on the live fat beast, and eventually on the carcass. Where possible the carcass is followed further to the butcher's shop from which the meat is eventually distributed to the consumer, and extra information on the proportion of the various cuts and the suitability of the meat may be obtained.

For the purposes of this survey attention is being concentrated on beef arising from dairy herds as this must contribute a good deal towards the total of home-killed beef and because few accurate data are available regarding the quality of beef from such sources. From figures given earlier in this paper it appears that approximately 65 per cent. of the animals in the milking herds of England and Wales are either Friesians or Dairy Shorthorns. Most attention is being focused on steers of these two breeds, and cattle arising from crossing beef bulls on cows of these breeds. While it is accepted that good carcasses of beef can be produced from Dairy Shorthorn and Friesian steers and their crosses there is no precise information about the variation in quality within these breeds, how the crosses compare with the purebreds or the effect of different environmental conditions on the type of carcass produced. In selecting farms from which to obtain data preference has been given to those with a large dairy herd from which both pure-bred steers and also some cross-bred steers (i.e. out of the dairy cows by a beef bull) are being reared and finished for beef. In this way it will be possible to compare, say, Friesian carcasses with those from Angus × Friesian cattle bred, reared, and finished under the same conditions. During each of the next two years it is hoped to follow at least 1,500 cattle, but there may be considerable losses of data through cattle being sold by auction, and individual beasts being purchased for slaughter in some distant part of the country. So far as this survey has progressed (it was commenced in the spring of 1956) this source of loss although annoying has not assumed serious proportions.

A portable weighing machine is now available and will be used to weigh the cattle at various stages of life on the farms co-operating in this study. By this means, with weights taken at three- or four-monthly intervals, it will be possible to assess the live-weight increase of cattle on various types of winter feeding and summer grazing and also to compare the rate of gain of pure-bred steers with their crossbred fellows on the same type of feeding and management. Over a few years much valuable information on growth-rates of the various sorts of cattle involved in this work may be obtained, covering far more cattle than would be possible under the conditions of an experiment conducted on one farm. Although such a survey cannot give such precise information on certain details as

the type of experiment now being conducted on the Ministry of Agriculture Experimental Husbandry Farms at High Mowthorpe and Rosemaund in which groups of Dairy Shorthorn and Friesian steers and steers sired by Hereford or Aberdeen Angus bulls out of Dairy Shorthorn or Friesian cows are being reared on the same feeding treatment [5], it will provide a good general picture of growth and type of carcass produced under a wide range of practical farming conditions.

Carcass Measurements

In this work the records of the live animal include live weight immediately prior to slaughter, and where practicable an estimate of the condition and level of fatness is made by the scoring technique used in the Cambridge beef experiments [3]. After slaughter the carcass weight is obtained, and hence dressing percentage. Both sides of the carcass are measured to obtain a picture of the size and proportions and of the level of finish, the measurements taken being:

Length of side	(pubis to first rib)
length of leg	(metatarsals to pubis)
length of tibia	
width of thigh	
depth of thigh	
length of radius-ulna	
depth of thorax	(maximum width through chest of hanging side)

When the sides are quartered between the tenth and eleventh ribs, the length of hindquarters and length of forequarters are also taken so that measurements are available for comparison with those of imported quarters of beef. Measurements of the 'eye muscle' are taken at the tenth rib cut on the forequarter and include length and width of cross-section of eye muscle, thickness of subcutaneous fat over muscle one inch in from the median line and also over the thinnest part of the eye muscle.

The weights of fore- and hind-quarters of each carcass are collected and the ratio of fore to hind end calculated. In addition a visual assessment of the carcass is made, and marks are allotted by eye on a standard scale (0–10) for each of the following points:

1. Level of finish of side.
2. Length and fullness of loin.
3. Fullness of topside.
4. Amount of cod fat.
5. Size of kidney knob.
6. Amount of internal fat apart from kidney fat.
7. Degree of marbling in eye muscle.

A few of the carcasses are followed into the butcher's shop, and broken down in a standard way into butchers' joints which can be weighed to

give the percentage of each in the carcass. This is possible only with a few locally-killed animals purchased by butchers who are able to cut up a whole side of beef in a day. In many small businesses, a quarter of beef is hung in the refrigerator and a joint taken from it at intervals as required.

In any research concerning meat the question of a standard or yardstick is bound to arise and is not an easy question to answer. Quality in meat is not easy to define. Hammond [6] defines it as that which the public like best and for which they are prepared to pay more than average prices. The survey carried out by Pomeroy [7] on consumer preference for beef showed that the majority of people preferred beef which was well finished but not overfat. In general, young tender meat is sought rather than old more highly flavoured meat which is likely to be tough unless hung well and properly cooked. One of the more difficult tasks of the meat producer is to obtain just the right amount of fat on the carcass; a sufficient amount so that the meat does not dry up but remains succulent on hanging and cooking, and not so much that some of it has to be pared off by the butcher before it is sold. The latter is a wasteful carcass for the retailer, as any fat pared off has to be sold at a much-reduced price.

Comparison with Argentine Chilled-beef Carcasses

In 1939 the Smithfield market demanded a 600 lb. carcass containing not more than 15 per cent. bone, 30 per cent. fat, and a dressing percentage of 57 per cent., from a live weight of about 9½ cwt., which was comparable with good Argentine beef. The Argentine chilled carcass of 600 lb. is killed at an average age of 23 months [8] from a good type of beef animal which has been reared without any serious check in growth and finished on grass or lucerne. The Argentine chilled beef of this size now coming into this country is quite well finished but not over-fat and has the advantage that by the time it arrives in this country it is well matured. Consequently it has been entirely acceptable to many consumers. As these Argentine quarters of beef have much to commend them from the point of view of quality, finish, size, and amount of fat it was decided to weigh, measure, and visually assess a considerable number of chilled fore- and hind-quarters which were described by the trade as being of good quality. Subsequently the quarters are cut up into joints by the usual Home Counties style of cutting, and the joints weighed. During the course of this investigation all the Argentine beef has been examined in one shop (of a firm having a large number of retail shops and dealing in considerable quantities of chilled beef) and all the cutting done by the same butcher to eliminate as far as possible errors due to cutting. The figures obtained from these Argentine quarters will be used as a yardstick against which the carcasses obtained in the survey can be assessed. Gradually a picture is being built up of the measurements, &c., of what might be described as the 'ideal side'. At fairly frequent intervals further Argentine quarters are being examined to keep the standard of assessment uniform and to watch for any changes in the Argentine chilled beef itself.

Preliminary Results

This study of beef cattle produced from dairy-bred calves on commercial farms and the type of carcass resulting is in its infancy but a few of the results obtained to date may be of interest.

To be competitive home-killed beef must be produced at a reasonably low cost. On most farms this involves making the utmost use of grass and cheap by-products both during the growing stage and in final finishing. There can be no doubt that beef must be cheaply produced but if the cattle are to be finished on grass what is the right treatment for autumn-born calves? Should they be slaughtered at the end of the second summer weighing from 8 to 10 cwt., even if unfinished, or should they be kept through a further winter and finished on grass the following summer at between $2\frac{1}{2}$ and 3 years old and weighing from 11 to 14 cwt.? A third alternative would be to winter-fatten the cattle between 2 years and $2\frac{1}{2}$ years old but this can be done cheaply only where certain by-products are available. Traditional yard feeding, using a good deal of concentrates, whether home grown or purchased, tends to be too expensive.

Many farmers find that their autumn-born Friesian steers get very big by the time they are fat on grass at $2\frac{1}{2}$ to $2\frac{3}{4}$ years old. The present demand is mainly for lighter-weight cattle (8–10 cwt.) killed at 2 years old. One wonders therefore whether it would be worth while to slaughter Friesian steers at 2 years old or just under, off grass at the end of the summer, even if they are not really finished, to prevent them from getting too large if kept for another season. How does the meat from a 2-year-old 9-cwt. Friesian steer, killed before the bullock is mature or finished, compare with that of the 600-lb. chilled Argentine carcass? In practice, farmers do not sell their fattening cattle without a certain amount of finish, so there is no recorded information on this question.

As a preliminary investigation two steers (a Friesian and an Angus × Friesian) were slaughtered, examined, and the carcasses jointed for comparison with Argentine chilled beef. It would not be reasonable to compare these with prime Scotch beef, but it seems fair to put them alongside Argentine beef for comparison. The two steers chosen were part of a bunch of Friesian and Angus × Friesian steers being reared for beef on a farm in Northamptonshire which is co-operating in the study already described. The bunch had a typical history for this farm and indeed for many others where dairy-bred calves are reared. The calves were autumn-born in the large Friesian herd, reared on the pail with milk replaced at about five weeks by milk substitute and supplemented with hay and concentrates. At six months they were turned out to grass and during the following winter were yarded as stores. At the end of that winter ten cattle (5 Friesians and 5 Angus × Friesians) were selected to make a bunch to graze together during their second summer so that weights might be recorded. When turned out on 1 May 1956 the Angus-cross steers averaged 833 lb. and the Friesians 761 lb., the ages being 19 and 15 months respectively. From turning out until August the Friesians gained in weight at an average of 2·10 lb. per head per day

compared with 1·68 lb. for the Angus × Friesians. At the end of August two cattle, one pure-bred and the other a crossbred, were selected by the farmer as being typical of their group. These were weighed and sent to Cambridge for slaughter so that the carcasses could be jointed in the same place and by the same butcher who had been cutting up Argentine quarters for this investigation.

The eight remaining cattle were kept for normal fattening, being run on grass until the end of November and then yarded for final finishing. In the yards they were fed pulped mangolds, *ad lib.* hay, 4 lb. concentrates per head daily, and straw to appetite. By the end of January six of the cattle were fit for slaughter, but two (one of each breed) required a further month on this treatment to reach the same stage. The average live-weight gains of the cattle are set out in Table 1.

TABLE 1. *Average Live-weight Gains per Day*

Feeding	*Friesians* (*lb.*)	*Angus* × *Friesians* (*lb.*)
1 May–31 Aug. (grass)	2·10	1·68
1 Sept.–8 Nov. (grass)	1·41	0·76
8th Nov.–22 Jan. (3 weeks on grass + concentrates. 8 weeks in yards).	1·23	1·18

The six cattle were slaughtered on 23 January and were described by the meat wholesalers as 'not completely finished, but just what the butcher requires nowadays'. Before slaughter one typical animal of each breed was selected by the farmer from this group and the left side of each was brought to Cambridge for jointing in the same way as had been done for the two immature cattle five months earlier. To complete the picture the carcass of a fully mature Friesian had also been jointed in a similar manner. This fully finished bullock had been reared in the beef experiment on the University Farm. It was autumn-born, reared by multiple suckling supplemented by concentrates and hay, and then spent its first summer on grass. After two winters of store feeding in a yard with a summer's grazing in between, it was finished off grass in the summer of 1956, weighing almost 13 cwt. at 33 months old. This mature bullock was a good type of Friesian and nicely finished (see Figs. 1, 2, 3, Plate 7). There are therefore available for comparison with chilled Argentine beef:

1. two immature cattle described as being in good store condition, well fleshed but not finished and certainly not fat;
2. two 2-year-old beasts, well fleshed, reasonably well finished but not fat (see Fig. 4, Plate 7);
3. one fully mature animal fully finished.

After cutting the quarters from the left side into joints in the same way, the weight of each joint has been expressed as a percentage of the quarter to give the relative proportions of each joint. These results are shown in Tables 3, 4, and 5.

TABLE 2. *Comparison of the Individual Animals*

	Chilled Argentine	*Immature Friesian*	*Immature Angus × Friesian*	*2-year-old Friesian*	*2-year-old Angus × Friesian*	*Fully mature Friesian*
Age (months)	23*	19	24	23	27	33
Live weight (lb.)	1,040*	1,078	1,078	1,134	1,183	1,440
Carcass weight (lb.)	582	576‡	581‡	613	669	815‡
Av. weight of forequarters†	139	138	138	148	170	194
Av. weight of hindquarters†	152	150	152	158	160	214
Dressing-out percentage	56*	53·6	53·9	54·1	56·6	56·6

* Average figures quoted in the literature.
† Sides quartered between the tenth and eleventh ribs.
‡ See Figs. 5, 6, 7, Plate 8.

TABLE 3. *Hindquarters (left side). Weights of Joints expressed as a Percentage of the Weight of the Hindquarter*

	*Argentine chilled**	*Immature*		*2-year-old*		*Fully mature Friesian*
		Friesian	*Angus × Friesian*	*Friesian*	*Angus × Friesian*	
Weight of hindquarter (lb.)	152	150	153½	156½	159½	214
Cod fat	2·93	2·23	3·33	2·75	3·84	3·68
Flank	8·44	6·04	6·67	5·63	5·68	6·37
Kidney suet (less kidney)	4·70	2·73	4·76	4·47	4·11	6·42
Rump	16·03	15·81	16·09	16·22	16·30	13·96
Rump fillet	2·47	2·03	2·52	2·24	2·35	2·10
,, bone	2·42	2·65	2·07	2·64	2·19	2·16
Channel suet	0·67	1·41	1·54	1·20	1·02	0·93
Trimmed rump	11·47	9·72	9·96	10·14	10·74	8·77
Loin	18·40	18·55	18·85	18·41	19·44	20·03
Chump end	10·56	12·09	11·74	8·71	9·33	10·52
Wing end	7·84	6·46	7·11	9·70	10·11	9·51
Hind shin	8·84	9·15	7·92	8·39	8·31	8·29
Bone (% of shin)	42·00	48·00	46·00	46·00	41·5	46·00
Meat ,,	58·00	52·00	54·00	54·00	58·5	54·00
Aitch bone	1·35	1·41	1·34	1·40	1·25	1·40
Thick flank	9·44	10·72	9·18	8·87	9·24	8·82
Topside	12·23	16·72	15·20	15·97	15·44	15·0
Silver-side (boned)	13·46	11·80	12·27	12·78	12·30	11·94
Bone (femur)	3·53	3·93	3·54	4·23	3·29	3·38

* Average of four hindquarters.

It must be realized that in dealing with single animals one may possibly be misled, and this experiment must be repeated with several batches of cattle to ensure that the result is a real one. However, bearing this limitation in mind and allowing for slight variations arising during

TABLE 4. *Forequarters (left side). Weights of Joints expressed as a Percentage of the Weight of the Forequarter*

	Chilled Argentine*	Immature		2-year-old		Fully mature Friesian
		Friesian	Angus × Friesian	Friesian	Angus × Friesian	
Weight of forequarters (lb.)	139	142	141	146	169	196
Thin flank and brisket	20·95	17·73	19·01	20·63	20·38	17·07
Shin	5·65	6·89	5·98	6·68	5·77	6·40
Clod	11·80	12·20	13·12	10·87	11·83	11·91
Sticking	8·65	9·57	8·51	8·39	7·91	8·72
Fore rib piece	11·31	13·39	13·29	10·62	9·32	12·22
Top rib piece	14·54	13·61	13·38	15·50	15·64	16·94
Back ribs	27·10	26·60	26·71	27·31	29·14	26·74

* Average of four forequarters. These are unlikely to be from the same animals as the hindquarters in Table 3.

TABLE 5. *Weights of Expensive Joints, Fat and Bone expressed as a Percentage of the Weight of the Quarter*

	Chilled Argentine*	Immature		2-year-old		Fully mature Friesian
		Friesian	Angus × Friesian	Friesian	Angus × Friesian	
Hindquarter						
Total of expensive joints (trimmed rump, fillet, loin, topside, thick flank)	54·01	57·74	55·71	55·63	57·21	54·72
Total of internal fat trimmed during jointing (cod fat, kidney and channel suet)	8·30	6·37	9·63	8·42	8·97	11·03
Total of main bones removed during jointing (rump and aitch bone, femur and tibia)	11·31	12·69	10·13	12·14	10·18	11·05
Forequarter						
Total of expensive joints (fore rib, back rib, and top rib piece)	52·95	53·60	53·38	53·43	54·10	55·90

* Average of four quarters.

cutting, the similarity of the proportions of the joints in all six types of cattle is striking. One of the most obvious differences is the amount of fat trimmed during the jointing of the hindquarters. This ranges from 6·37 per cent. in the immature Friesian to 11·03 per cent. in the mature Friesian. The kidney suet is primarily responsible for this variation and this large kidney knob is a common feature of mature Friesian cattle, in fact of mature dairy-bred steers generally. The Friesian steer which was slaughtered five months after the immature animal, and the two Angus × Friesians, are intermediate between the two extremes, and more closely resemble the Argentine hindquarters. The position regarding the other fat deposits is summarized in Table 6.

TABLE 6. *Back Fat Measurements taken at Cut between 10th and 11th Ribs (mm.)*

	*Argentine chilled**	*Immature*		*2-year-old*		*Fully mature Friesian*
		Friesian	*Angus × Friesian*	*Friesian*	*Angus × Friesian*	
Thickness of back fat (1 in. in from median line) .	14	4	11	7	10	13
Thickness of back fat (over thinnest portion of eye muscle) . .	11	2	5	9	6	8
Marbling fat in eye muscle (*longissimus dorsi*) .	good	none visible	poorly developed	poorly developed	moderate amount	moderate amount

* Average of measurements from four hindquarters jointed.

These fat deposits follow the same trend as the trimmed fat deposits. The amount of fat in the Argentine quarters approaches the ideal in the eyes of the meat trade, and of many consumers. The immature Friesian lacks marbling fat and back fat. The mature Friesian which had arrived at much the same level of fatness in back fat and marbling fat as the Argentine beef had put on a very large amount of trimmable fat in addition. The Angus-cross animals and the 2-year-old Friesian are intermediate in position and may represent a degree of fatness and marbling towards which public opinion will move in selecting beef.

On the basis of the figures quoted above a butcher will trim 8 lb. of suet from each 100 lb. of Argentine hindquarter compared with 11 lb. of suet from each 100 lb. of mature Friesian hindquarter. This means that assuming both hindquarters cost the same price per pound, the retailer will have to charge a higher price for the Friesian meat than for the chilled to cover the extra loss due to the sale of trimmed fat at a lower price than it cost in the quarter. On this factor alone a butcher is justified in paying three shillings a live hundredweight less for a 13-cwt. Friesian bullock than for one weighing 9–10 cwt.

One of the criticisms often levelled against the Friesian as a beef animal is the large amount of bone in the carcass. The figures in Table 5 do not support this contention on a weight basis, the proportions being remarkably similar to those for the chilled beef. It appears that the immature and 2-year-old Friesians were less finished than the Angus × Friesians of approximately the same age and consequently had a higher percentage of bone in the hindquarter. These conclusions must be regarded as tentative and require confirmation from many more examinations of this sort.

The totals of expensive cuts in the hindquarters show remarkable similarity between the Argentine and mature Friesian carcasses. The young animals seem to be at an advantage in this respect when compared with the more mature animals, due to a better development of topside, but this single figure should be treated with caution. The mature

Friesian is heavier in the shoulder than the other types and shows a slight advantage in the proportion of more expensive cuts of the forequarter. It would appear that further studies of this sort not only on Friesian steers, but involving other Friesian crosses and also Shorthorns and their crosses would yield much-needed information and it is hoped to continue this work.

Cooking and Tasting Quality

Cooking and tasting quality have always been difficult to judge accurately, as they are subject to variations in human appreciation. However, selected joints from the five bullocks (3 Friesian, 2 Angus × Friesian) were cooked and tasted by a small panel. It was found that the immature Friesian meat needed more basting during cooking to prevent it drying; it was reasonably tender but lacked flavour and the cold joints tended to dry up more quickly than those of the other types of cattle. The meat of the immature Angus × Friesian ate quite nicely, but was a little dry and had little flavour. The texture of the meat and its tenderness were satisfactory. The mature Friesian produced satisfactory beef, tender and with reasonable flavour, but inclined to be slightly dry. The 2-year-old Friesian and Angus × Friesian were very similar to the mature Friesian in most respects. The Angus-cross beef was always more attractive to look at with better texture and cooking qualities than its pure-bred Friesian counterpart. The general impression of the panel was that as consumers they would not grumble if their meat was never poorer than that supplied by the three most mature animals. The joints from all these animals had been hung a reasonable time before cooking and consequently compared favourably for tenderness with the Argentine chilled, which has the advantage of enforced conditioning during transit.

The butchers who saw these carcasses and joints expressed the opinion that the two immature animals gave joints of a very saleable size, they were lean enough to appeal to the public, but they felt that more finish was necessary to make sure that the meat cooked tender. The joints from the animals which had been run on for an extra five months were much better in this respect but could still be slightly faulted. They agreed that the beef from the mature Friesian was entirely satisfactory but it was difficult to cut such a large side into suitable joints for the average retail trade. They felt that this experiment of slaughtering young dairy-bred cattle to compare with older cattle was well worth repeating.

It would appear that the 2-year-old autumn-born Friesian steer is the right weight for the butcher but needs the finish of the mature Friesian without the large amount of trimmable fat. It is hoped that during this survey and from the experiments in progress at Cambridge information will be obtained which will point the way towards overcoming this difficulty. To fatten such a bullock in yards for three to four months on a high plane of feeding might solve the problem from the butcher's angle, but from the producer's angle may be entirely unprofitable.

Economic Considerations

Yard-fattening materially increases the cost of production and unless there is a proportionate rise in the sale value of the bullock it cannot be upheld on economic grounds. The producer's side of the business of growing beef from dairy-bred cattle needs much careful study, particularly from the financial standpoint. It is no use the butcher demanding a particular weight of carcass and degree of finish if such is unprofitable to produce. Throughout most of 1956 beef cattle were sold at comparatively low prices and many producers lost money on their fattening cattle. It is worth while to examine the financial implications of the small-scale test described above.

The immature Friesian steer killed at the end of August had cost approximately £57 (including £8 charged for the calf). Assuming it were finished when sold at the end of the summer weighing 9 cwt., it would have made £63 (at £7 a live cwt.), leaving a margin of £6 over cost. Such a bullock could be kept on and sold fat off grass early in the following summer, for being older it would finish sooner than a younger beast and might even go fat in June when the price of fat cattle is usually higher than later in the summer. From September until Christmas in an open autumn, such as occurred in 1956, such cattle could be maintained on grass for little more than the cost of labour in overlooking them. The grass these cattle eat in the back end of the year costs very little, for if the cattle had been sold the grass would probably have been wasted. Few farmers would buy cattle to eat-off this grass. Yet these cattle if kept would continue to put on weight in most seasons, and put it on very cheaply indeed. For example, from 1 September to the middle of November the eight remaining cattle increased in weight at the following rates per day: Friesians 1·41 lb., Angus × Friesians 0·76 lb. On Cambridge University Farm a bunch of Friesian steers of similar age put on a steady 1·65 lb. per head per day from mid-July to mid-December. A reasonable charge for the three months grazing from September to December would be £1. 10*s*. 0*d*. per head. For the remainder of the winter the bullocks could be outwintered on suitable farms or wintered cheaply in straw yards on such foods as a little hay, sugar-beet pulp, and a good deal of straw with very little other food. In yards this second part of the winter would cost about £13, for the aim would be to turn the cattle to grass at the earliest opportunity in the spring. Charging £2. 10*s*. 0*d*. for the grazing until it is sold fat, say, in June, the additional cost of keeping the bullock is £17, giving a total cost of £74 at 32–33 months old. If the bullock, now 13 cwt., can be sold at £7 a live cwt. it will realize £91, leaving the producer a margin of £17. This is nearly three times the previous margin and appears much more profitable. To give the same margin of profit, the 9-cwt. animal must sell for over £1 per cwt. more than the 13-cwt. beast, and to make the sale of the lower-weight animal attractive the price differential needs to be about 30*s*. a live cwt. (equivalent to 6*d*. a lb. dead weight). Even if the heavier animal sells for £6. 10*s*. 0*d*. a cwt. (10*s*. less than the price credited to the younger beast), it would still leave a margin of £10. 10*s*. 0*d*. In fact,

during much of 1956 the average price realized by light-weight cattle was not more than 3*s*. to 5*s*. a live cwt. higher than that paid for heavy-weights in many auction markets.

The remainder of the group of cattle reared in Northamptonshire from which the pair of selected animals had been killed were run on grass until the end of November, with concentrates fed in the last three weeks of this period. They were then yarded and fattened by the end of January 1957. The total cost of these bullocks is estimated to be £71. After Christmas 1956 there was a fairly steep rise in beef prices and these cattle were sold in time to reap the benefit of this. They were sold for £9 a live cwt. and realized £90 a piece—a margin of £19 over cost. This is an all-too-rare example of winter fattening making a profit, though it must be remembered that the cattle had not been fully fattened nor had they been yarded for a very long time. In the previous winter, however, such cattle would have made about £2 a live cwt. less and with approximately the same cost would have made a loss of £1 a head. This is just one example of the many financial problems which face the beef producer; selling cattle at the right time is an important factor affecting the profitability of the enterprise. In all these calculations the guaranteed support payments for fat cattle by the government have been included in the sale price of the cattle but no account has been taken of the calf subsidy, or subsidy payments for attestation. The figures for the cost of production up to 18 to 24 months have been based on figures obtained on seventy-five Yorkshire farms in 1954–5 by the Economics Section of the Leeds University Department of Agriculture [9]. Other surveys carried out by the Department of Agricultural Economics at Bristol support them [10]. The cost of production beyond eighteen months was estimated from the costs actually incurred in the cases cited.

Another financial problem concerns the difference in cost of rearing spring- and autumn-born calves, most authorities agreeing that the cost of rearing to 2 years old a store born in the spring is some £6 to £10 higher than that for the autumn-born animal. This is largely due to the fact that the autumn-born calf may be reared cheaply on grass in its second six months whereas the spring-born calf does not go to grass until it is a year old. In addition, there may be an added difference in cost owing to the higher price of spring calves compared with those born in the autumn. When should these cattle born at different times of the year be marketed to give a suitable article for the butcher and at the same time to give a reasonable return to the producer, bearing in mind different costs of rearing and variations in beef price due to season, seasonality of imports, &c.?

It is not the purpose of this paper to discuss at length the financial implications of the various possibilities, but such questions as these must be asked, particularly by producers.

Cheaper Wintering Systems

It is clear that home-killed beef must be produced cheaply to be competitive. Many attempts are being made by farmers to devise

methods of reducing the cost of the winter period (the most expensive period) for beef cattle, both for the store animal and also for fattening where this is done in winter. Such methods include the self-feeding of silage, outwintering on sugar-beet tops, kale, foggage, and other materials and the use of straw pads. Several novel and somewhat unorthodox techniques to cheapen the wintering of cattle have been developed by farmers in recent years, and some of these when viewed through traditional eyes sometimes appear to involve a certain amount of risk either to the cattle or to the land, or possibly to both. As a further part of the survey work attention is being paid to the subject of cheaper wintering and promising techniques are being studied on the farms concerned to see how such methods fit in with the resources of the farm and the system of farming employed and also to what extent such methods could be applied elsewhere. Arising from this line of inquiry it may seem desirable at a later date to conduct controlled experiments on certain aspects of this subject, but clearly in the first instance all reasonably possible means of cheapening the various stages of the beef animal's life, particularly the winter periods, must be studied under commercial farming conditions.

During the course of the survey it is hoped to obtain a good deal of information concerning the variation in type of carcass produced when cattle born at various times of year are finished at different ages and on different systems of rearing and fattening. It should be possible to assess the costs and returns of the various alternatives from the accurate detail collected by agricultural economists. In this study both pure-bred and crossbred cattle are included. It may well be that some of the problems concerning weight and age for finishing of dairy-bred steers may be solved, or at least eased, by changes in breeding, such as, for example, the use of a certain type of beef bull. Further work along the lines of this investigation will shed light on this aspect.

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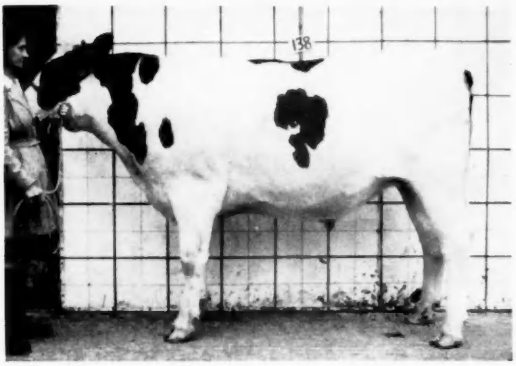

FIG. 1. Mature Friesian steer (33 months old) just prior to slaughter in July (see Tables 2, 3, 4). Same scale as Fig. 4

2

FIG. 2. Overhead view of same steer. Same scale as Fig. 3

3

FIG. 3. Rear view of same steer. Same scale as Fig. 2

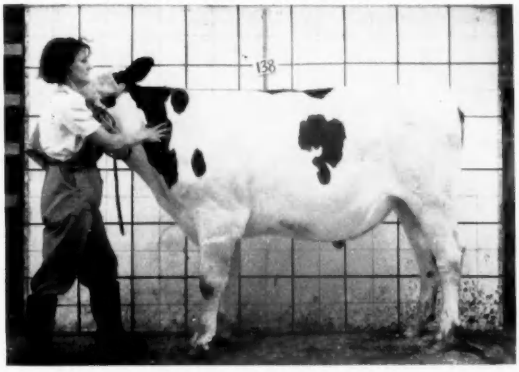

FIG. 4. The same Friesian steer at 23 months old at the end of previous summer. Same scale as Fig. 1. (In similar condition to the immature Friesian which was killed; an unfinished store)

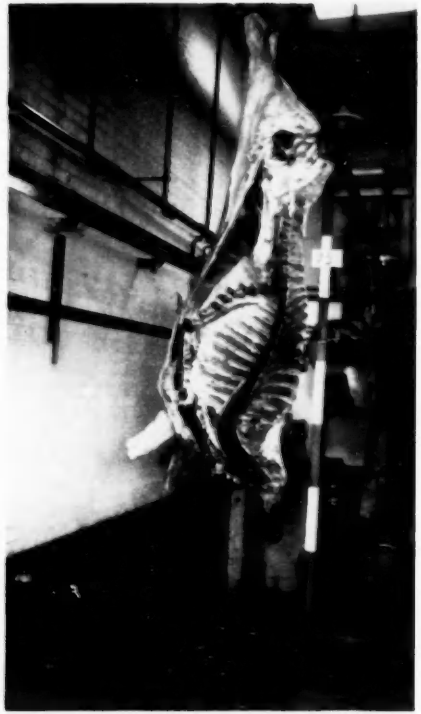

FIG. 5. Left side of immature Friesian (19 months)

FIG. 6. Left side of immature Angus × Friesian (23 months)

FIG. 7. Right side of mature Friesian (33 months) shown alive in Figs. 1, 2, and 3

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Plate 6 (Fig. 5c), facing p. 321:—

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but less than in *g*.
Surface less deformed than in *g*

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but less than in *a*.
Surface less deformed than in *a*

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Page 326, lines 23 and 24:—

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